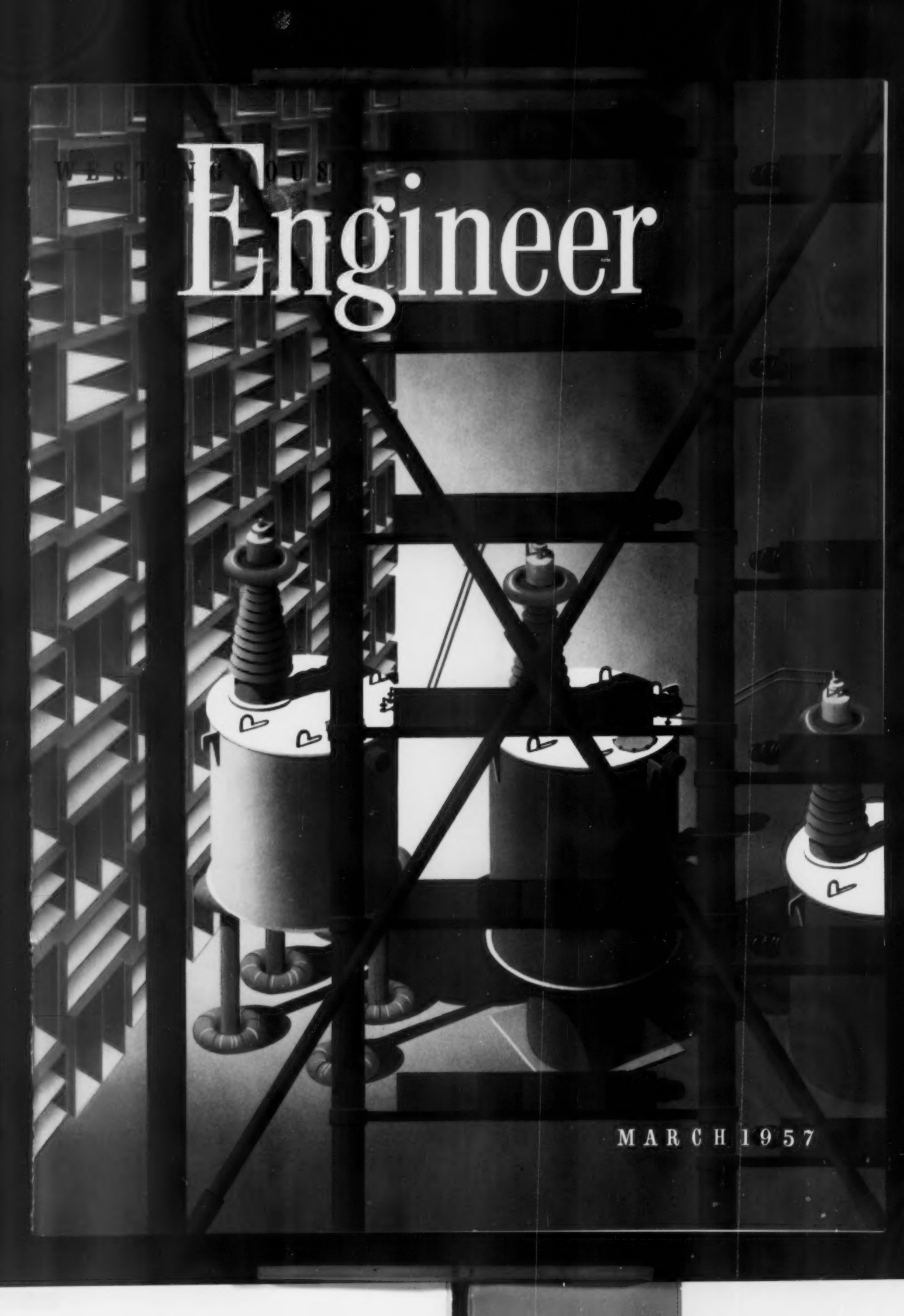

W. S. T. N. G. H. O. U. S.
Engineer
MARCH 1957

A LETTER TO COLLEGE SENIORS

About now, several thousand college seniors are mulling over the relative merits of their various job offers. Meanwhile the organizations that made the offers are just as carefully reviewing their prospects. Normally these are difficult decisions for both the individual and the company, because each side has a lot to lose by a wrong choice. In these days of technical manpower shortage, however, the issues are sometimes clouded, the decisions more difficult.

Long experience in interviewing and hiring graduates directly from colleges and universities gives us a good picture of both sides of the decision. On this basis we'd like to offer a few suggestions to those graduates now making up their minds. They apply no matter what field you may want to specialize in.

Study the companies from which you have offers. And we use the word "study" literally. Tackle this job as thoroughly as you would any important task. Study the history and traditions of the company; make an evaluation of its future. Investigate its reputation through every source you can find. Don't be swayed too much by any one good or bad feature you may discover—unless you feel it is a critical factor. Add up your positive and negative facts carefully and make sure that you weigh their relative importance. Listen to everyone's opinions—but evaluate them carefully before you make up your mind.

Look for Opportunity. Look beyond the immediate job you are offered. Look for the chance to grow professionally, for the opportunity to show your ability. Does the company have the reputation for providing these opportunities? Does it, for example, provide opportunity for continued education; does it have programs to assist with your personal and professional advancement? Does it encourage participation in professional societies? Does your prospective employer have a specific means for helping you to get oriented in the company, and to see that you find the right position? If the company does plan for your future—in these and other ways—it will not hesitate to tell you about those plans. As a double check, find out the progress of friends or fellow alumni in that company, if possible.

Look at the Future. The speed with which you advance professionally and organizationally depends primarily on two things—utilization of your ability, and the future success of the company itself. Is the company in a field or fields that are expected to grow? Is it an industry with sharp ups and downs, one on the decline, or is it on the increase? You may find strong reasons for going into a company in any one of these situations—but make sure you consider this factor carefully. Make sure the company is offering you a future, not just a job.

Obviously, these are questions, not answers. Most of the answers can be obtained—but the final task of analysis and decision rests with you. Each of you will not attach the same importance to these answers, for the answers must be weighed against your own personal aims, ambitions, and preferences. Choose carefully, choose wisely—and then tackle your new job with all the enthusiasm, ingenuity, and knowledge at your command. We wish you every success.

J. A. Hutcheson

VICE PRESIDENT, ENGINEERING

WESTINGHOUSE

Engineer

VOLUME SEVEN · NUMBER TWO · MARCH, 1957

In This Issue

The pros and cons of several different homogeneous reactor types, plus a progress report on the PAR project.

34 **The P.A.R. Homogeneous Reactor Project**
W. E. Johnson, D. H. Fax, and S. C. Townsend

Punched cards will soon direct the operation of a reversing roughing mill in Jones & Laughlin's Aliquippa Works.

40 **The Card-Programmed Control For Reversing Mills**
A. W. Smith

All of today's industrial feedback control systems operate on these same fundamental engineering principles.

42 **Feedback Control Principles For Industrial Drives**
C. G. Helmick

Both development and production testing will be done in this complete new transformer test facility.

47 **Transformer Test Center**

A new compressed-air breaker design incorporates features of both oil and air circuit breakers.

50 **A New Compressed-Air Circuit Breaker Design**
J. E. Schrameck and R. E. Kane

Reversing contactors have been eliminated in the Load-O-Matic crane control.

54 **A-C Crane Control With Load-O-Matic**
H. A. Zollinger

The availability of fresh water is a key factor to progress. This method of providing fresh water has promise.

58 **A Flash Evaporator For Distillation of Sea Water**
Y. S. Touloukian and R. L. Coit

X-Ray Machine Traces Atomic Changes in Metals—Meter Motor for Miniature Gyroscope—Cooling Aircraft Electronic Equipment—Etch Pits and Domain Patterns—Whiskers Aid Study of Atomic Forces—Long Line of Luminaires

61 **What's New**

The following terms, which appear in this issue, are trademarks of the Westinghouse Electric Corporation and its subsidiaries:

Load-O-Matic, Prodac

THE COVER

The checkerboard pattern of a sound chamber's walls, the ladder-like structure of a surge generator, and the solid mass of the cascade transformers were the design elements chosen for this month's cover. Combined, they form artist Dick Marsh's impressions of the new transformer test center described on page 47.

Editor . . . RICHARD W. DODGE

Managing Editor MATT MATTHEWS *Design and Production* JAMES G. WESCOTT

Editorial Advisors J. A. HUTCHESON, J. H. JEWELL, DALE MCFEATTERS

Published bimonthly (January, March, May, July, September, and November) by the Westinghouse Electric Corporation, Pittsburgh, Pa.

Subscriptions: Annual subscription price in the United States and possessions is $2.50; in Canada, $3.00; other countries, $3.00. Single copy, 50¢. Address all communications to *Westinghouse* ENGINEER, P. O. Box 2278, 3 Gateway Center, Pittsburgh 30, Pa.

Indexing and Microfilm: *Westinghouse* ENGINEER contents are regularly indexed in Industrial Arts Index. Reproductions of the magazine by years are available on positive microfilm from University Microfilms, 313 N. First Street, Ann Arbor, Michigan.

THE WESTINGHOUSE ENGINEER IS PRINTED IN THE UNITED STATES BY THE LAKESIDE PRESS, CHICAGO, ILLINOIS

Single-Region Aqueous Slurry Breeder Reactor

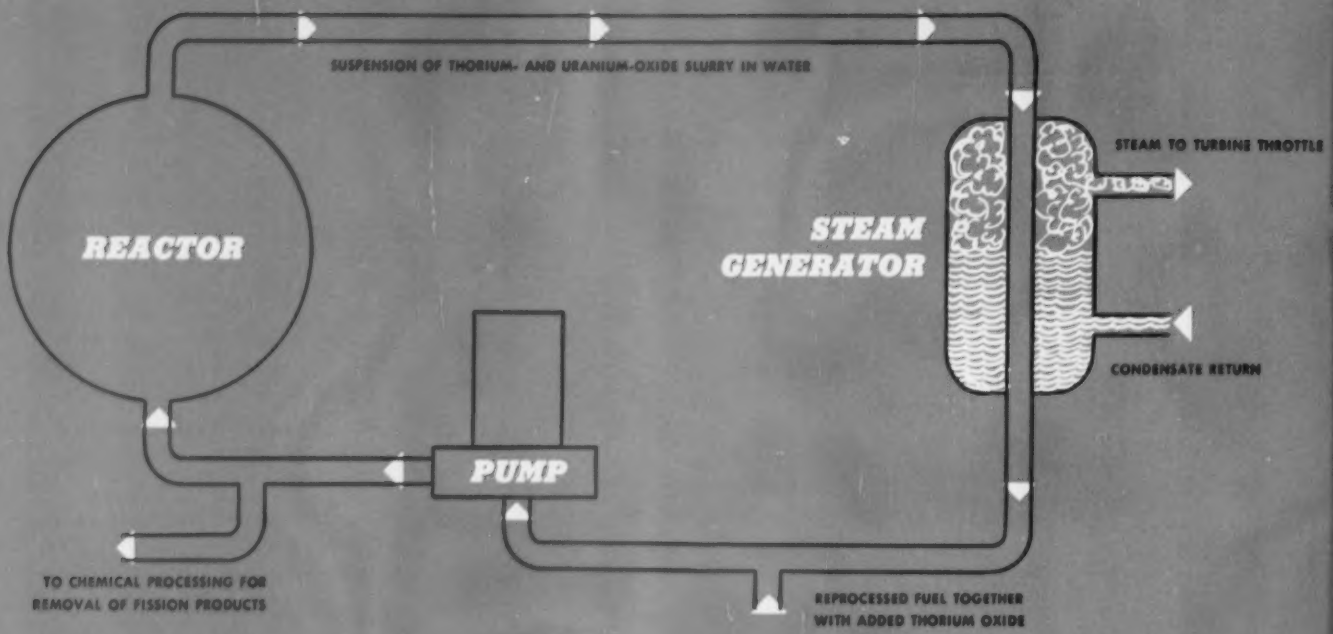
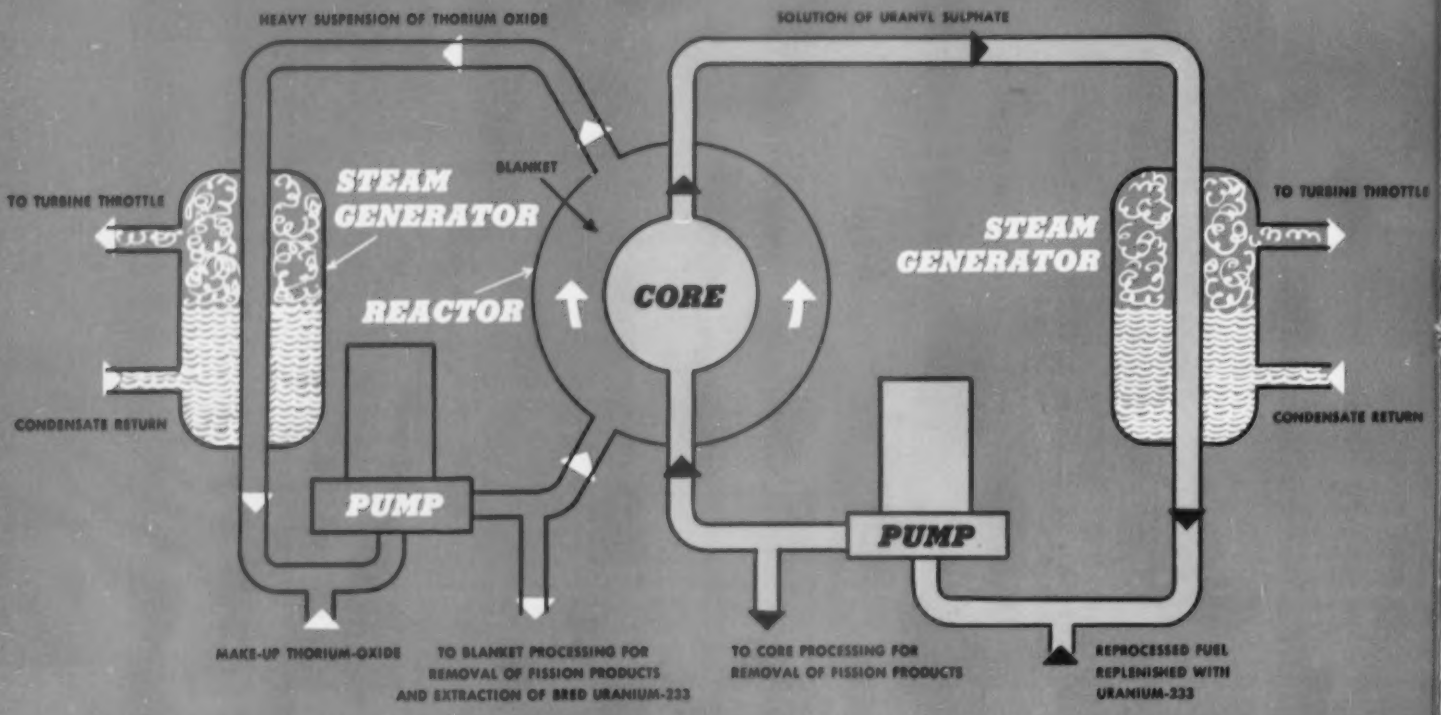

SUSPENSION OF THORIUM- AND URANIUM-OXIDE SLURRY IN WATER
REACTOR
STEAM GENERATOR
STEAM TO TURBINE THROTTLE
CONDENSATE RETURN
PUMP
TO CHEMICAL PROCESSING FOR REMOVAL OF FISSION PRODUCTS
REPROCESSED FUEL TOGETHER WITH ADDED THORIUM OXIDE

Fig. 1a

The P.A.R. Homogeneous Reactor

Fig. 1b



Two-Region Aqueous Breeder Reactor

W. E. JOHNSON
Manager

D. H. FAX
Assistant to Manager
P.A.R. Project
Commercial Atomic Power Activities
Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

S. C. TOWNSEND
Manager, Atomic Power Department
Pennsylvania Power & Light Company
Allentown, Pennsylvania

The Pennsylvania Advanced Reactor Project *is a major development effort jointly sponsored by Westinghouse Electric Corporation and the Pennsylvania Power and Light Company. Its function is to carry out the experimental and analytical studies leading to the design of an aqueous homogeneous reactor plant having an electrical output of 150 000 kilowatts. This plant is to operate on the PP&L system in Eastern Pennsylvania and is planned to be in operation in 1962.*

The origin of this project dates back to November, 1954. At that time Pennsylvania and Westinghouse, both operating under study agreements with the Atomic Energy Commission, joined forces to carry out their own evaluation of the five power-reactor concepts which had been proposed to that time. The major objective was to determine for each type its potentialities with respect to the production of competitive or nearly competitive electric power in the near future. The study showed the aqueous homogeneous reactor concept to hold forth such promise that the two Companies entered into a partnership agreement at the end of July 1955 jointly to finance and carry out this project. This article constitutes a progress report on the work carried out to date under this agreement.

Project

COMPARISON OF SEVERAL HOMOGENEOUS REACTOR TYPES

Type	Fuel	Basic Cycle	Comments
Simple Burner	Highly enriched U-235, as solution of uranyl sulfate.	Straight burning of U-235.	Relatively low plant cost but high fuel cost, making the total energy cost non-competitive.
Heavy Solution Reactor	Slightly enriched U-235 in highly concentrated uranyl sulfate solution.	Straight burning of U-235 plus conversion of U-238 to plutonium. Plutonium can be burned in place or sold as by-product.	While the fuel cost would be less than that of the simple burner, problems involving corrosion and thermal stability are more severe; hence probably not technically feasible in the immediate future.
Single-Region Slurry Reactor	Mixture of oxides of thorium and uranium, in slurry form.	Straight burning of U-235. Conversion of thorium 232 to uranium 233; U-233 can be burned in place or sold as by-product.	Can produce from thorium at least as much fissionable material as it consumes; consequently has excellent possibilities for competitive power.
Two-Region Slurry Reactor	Central core of highly enriched uranyl sulfate, surrounded by blanket of thorium-oxide slurry. Two fuels separated by core liner.	Straight burning of U-235 in core. Neutrons from core convert thorium to U-233; U-233 also fissions, thus producing more heat.	Can produce from thorium even more fissionable material than it consumes; consequently could possibly have negative fuel costs. However, the technical problems to be solved appear much more difficult than in the case of the single-region reactor.

The text of this article was abstracted from a paper presented at a joint session of the Nuclear Engineering and Power Division at the ASME Annual Meeting in New York on November 25, 1956.

▪ The words "aqueous homogeneous reactor concept" warrant some consideration. They encompass a variety of proposed systems, many of which have been actively studied. In many reactor types, the fuel, the moderator, and the coolant are physically separate and distinct. In the aqueous homogeneous reactor they are all intimately mixed. The moderator, either H_2O or D_2O—i.e., either ordinary water or heavy water—carries the fissionable material in either solution or suspension, and the whole circulates through a piping complex consisting of a reactor vessel, a heat exchanger, and a pump (see diagrams at left).

The reactor vessel is of such size that the quantity of fuel contained in it is equivalent to a critical mass and thus can sustain the fission process. The heated liquid is pumped to the heat exchanger where it gives up its heat to form steam in the secondary system and is then returned to the vessel to repeat the cycle.

In contrast to a fixed-fuel reactor, the homogeneous system offers a number of important advantages. The problem of transferring heat at very high fluxes from fuel

through cladding to coolant is obviated. Because of the absence of structural material within the core, more efficient use can be made of the neutrons born in fission. As the fuel is consumed, fission products can be removed and fresh fuel added continuously, in contrast to the down time required by solid-fuel reactors. Because fuel as well as moderator decrease in density with an increase in temperature, the homogeneous reactor can be inherently more stable with respect to power surges. Obviously, along with these advantages come a number of special difficulties, which will be discussed later.

Early studies indicated that four homogeneous systems should be looked into in some detail (see Table I). The first is referred to as *simple burner*. In this case, the fuel is highly enriched uranium 235 as a solution of uranyl sulfate. Since no fertile material, such as uranium 238, is present, no conversion or production of additional fissionable material can occur and hence the name simple burner. The plant costs for this process would probably be the lowest of the four to be considered, but since highly enriched fuel is burned, the resulting total energy costs would be prohibitive in most cases. At $25 per gram of uranium 235, for example, the cost of the consumed fuel itself would be approximately 5 mills per kwhr.

This high fuel cost would be reduced if slightly enriched uranium were used as the fuel. In this case the fission neutrons captured by the uranium 238 could be used to produce plutonium. The plutonium, in turn, could be used as fuel or sold as a by-product. To make this system economically feasible requires very high concentrations of uranyl sulfate, and hence this second type is called the *heavy solution* system. The heavy solutions used to date are extremely corrosive and in addition, have severe limitations with respect to thermal stability. As a consequence, the heavy solution reactor, while under active study at Oak Ridge National Laboratory and elsewhere, does not appear to be technically feasible for construction in the immediate future, but conceivably may be a longer term prospect.

The third system is similar to the second but operates on the thorium-uranium cycle rather than on the better known uranium-plutonium cycle. Thorium 232, upon capture of a neutron, converts to uranium 233, which is fissionable. Hence if the fuel in the systems described previously were replaced by a mixture of uranium and thorium, the uranium 233 formed could be used as additional fuel or sold as a by-product. In fact this system is capable of producing more new fissionable material than it consumes, and hence can be a breeder reactor. Unfortunately, the only soluble thorium compounds are not stable at reactor temperature and radiation conditions, and hence cannot be used as reactor fuels.

Thorium oxide, on the other hand, while insoluble in water is quite stable and considerable work has been done, principally at Oak Ridge, to demonstrate that thorium oxide shows real promise as a possible substitute for the solution. The principal problem is, of course, that the primary system and most of the auxiliaries must be designed to pump and handle a quasi-homogeneous suspension or slurry. There are at least two ways of building a slurry reactor. In the first of these, the thorium and uranium are in intimate mixture as oxides; this is called a *single-region* slurry reactor (see Fig. 1).

The fourth and last type under consideration is the *two-region* reactor. The reactor proper consists of a central core region, or seed, of a dilute solution of highly enriched uranyl sulfate in heavy water, surrounded by a circulating blanket of thorium-oxide slurry, and separated from it by a core liner. The major fraction of the fission heat is released in the core region, and neutrons passing through the core liner bring about conversion in the blanket. This system can be shown to have excellent breeding possibilities—even better than that of the single-region slurry type. The plant is somewhat more complicated than that of the single-region reactor because of the two interacting systems, but it certainly has other advantages in its favor.

The PAR project is concerned primarily with the single-region and the two-region reactors. Both have excellent possibilities of being breeder reactors and hence both have the possibility of attaining what so many people thought was the main attraction of nuclear power—zero or nearly zero fuel cost. If the capital and operating costs can be kept low enough, competitive power is at hand.

PAR Project Objectives and Organization

The primary objective of the PAR project today is to investigate and compare these two types including both technical feasibility and economics. On the basis of these investigations, one reactor type will be selected for detailed design and construction.

Unfortunately, adequate information to compare these two types of reactor plants does not exist. The PAR project program is designed to develop the necessary information, using that available from Oak Ridge and other existing AEC programs and developing any additional information needed.

The work falls naturally into three major categories. The first of these is the experimental program necessary to determine the physical and chemical properties of thorium and uranium oxide slurries. Here an economy of effort is possible. Oak Ridge has been engaged for several years in the intensive study of the properties of thorium-oxide slurries of the fairly heavy concentrations applicable to the blanket of the two-region system. On the other hand, less effort has been devoted to the investigation of the problems accompanying the use of lighter slurry, particularly that of mixed thorium and uranium oxides, appropriate to the single-region reactor. As a consequence extensive laboratories and test facilities have been set up at Westinghouse for the performance of this work.

The second category is that of the development of plant components. Here the same economy of effort was not possible. The work at Oak Ridge in this field has been concerned primarily with the development of components for the Homogeneous Reactor Test, an experimental reactor of approximately one-hundredth the thermal output of the one under consideration here. The problem of extrapolating such component designs and of developing new concepts appropriate to the larger plant is a major one.

The third category of work embraces that of plant design and layout. Here the project is completely independent. An adequate comparison of two types of plants can be made only if they are designed by the same group with the same general philosophy and priced using the same basic costs. As a consequence, a Reactor Analysis Section was formed for carrying out the overall system and nuclear design of both types of plants, and a Plant Engineering Section to make layout designs and cost estimates.

Chemical reprocessing of spent fuel is of course an important aspect of any reactor plant. For the homogeneous plant, a number of possibilities exist in this field—a reprocessing system can be integrated with the reactor plant itself or the fuel can be withdrawn batchwise and sent to a central reprocessing plant for treatment. The Union Carbide Nuclear Company was interested in studying these possibilities and early in the PAR project became a third partner.

Estimating the time required for developing the needed body of information in addition to the time required to design and construct the full-scale plant, 1962 was chosen as the earliest date by which the plant could be in operation. These estimates allowed four years for the detailed design, construction, and test operation of the plant. Thus by late 1957 or early 1958 enough information must be developed to enable a proper choice of the important plant design parameters.

Reference Design One

By the time the project was six months old, it became apparent that separate studies of reactor physics, systems engineering, component design, and plant layout and maintenance would not produce, in two years, the necessary information from which could be chosen the best plant with which to enter the second phase of the project. Consequently, a series of "reference designs" was instituted, whose first purpose is to coordinate the studies of our several groups by an early focussing of attention on several sets of particular ground rules, one set at a time; this will insure that at the end of the first phase of the project a body of self consistent information will be available on which to draw. The first of these reference designs points up the nature of some of the problems.

A one-line drawing of the primary loop of this reference design is shown in Fig. 2; some of the principal design parameters are indicated. The system circulates a mixed oxide slurry of a concentration of about 260 gm per kg of D_2O, corresponding to a solids concentration of about 3 percent by volume. In the reactor vessel the fission process releases 550 mw of thermal power, which in turn yields 150 electrical megawatts for an overall thermal efficiency of about 27.5 percent. The pressure vessel has an outside diameter of 15 feet and a wall thickness of 6 inches. Just inside the wall are a number of thermal shields, which absorb the major fraction of the gamma radiation issuing from the core. Those shields are cooled by a portion of the main slurry steam, thus reducing the thermal stresses that would otherwise result in the pressure-vessel wall. The electrically heated pressurizer maintains a system pressure of 2000 psia, which is well above the vapor pressure of the fluid in the primary loop. The pressurizer contains only D_2O and is separated from the surge chamber by a steam space, thus avoiding the caking that might result if the slurry itself were boiled.

Leaving the reactor vessel, the slurry branches into four parallel identical loops, only one of which is shown. Each loop can be isolated from the reactor by two pairs of dual stop valves, to permit certain types of remote maintenance to be performed without shutting down the entire plant. In the reactor vessel, part of the kinetic energy of the fission fragments is absorbed by water molecules, which are dissociated into deuterium and oxygen in the process. The major part of these radiolytic gases is recombined internally through the action of a suitable catalytic agent. About 10 percent is left unrecombined in order to help sweep out the gaseous fission products, principally xenon, which would otherwise lessen the efficiency of neutron utilization. These gases are removed from the main stream in the gas separator. The slurry gives up its heat in the steam generators, and is returned to the reactor vessel by the hermetically sealed canned motor-pumps.

Fig. 2—Principal design parameters of the primary loop of the first reference design.

Fig. 3—A schematic system diagram, showing the auxiliary sub-systems of the plant.

Fig. 2

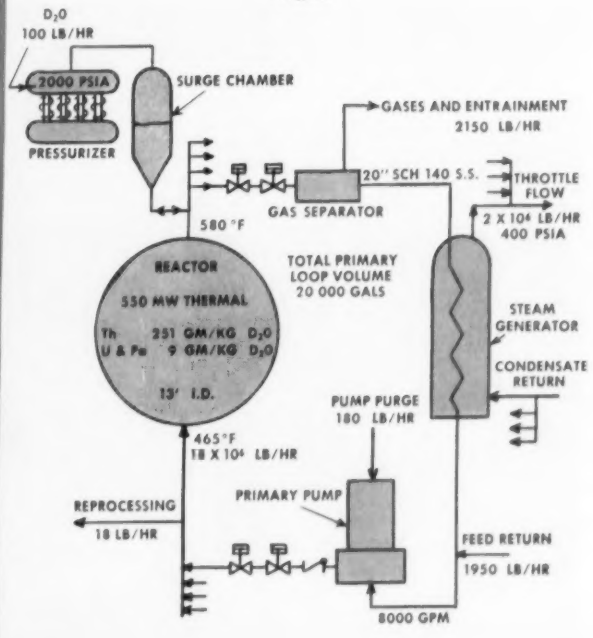
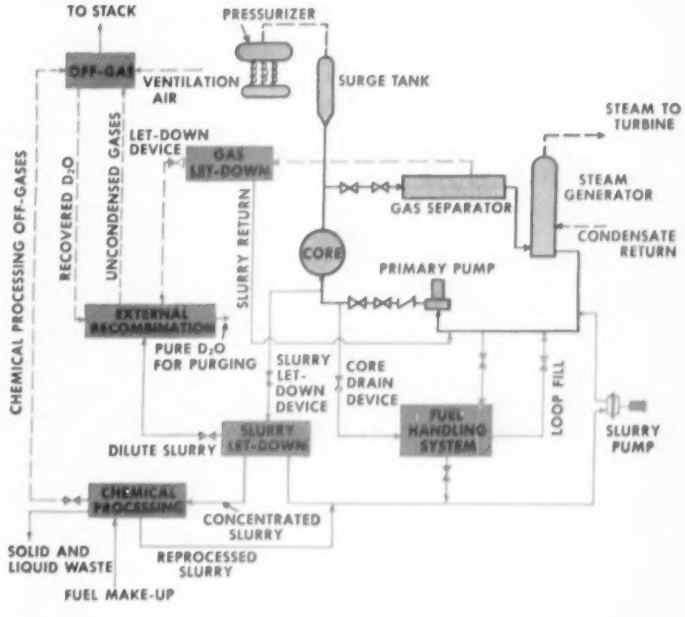


Fig. 3



Several fluid streams are shown entering and leaving the primary system. The largest single stream is the mixture of gases and vapor leaving the gas separators. A small stream of D_2O is introduced at the motor end of each primary pump to maintain the bearings free of slurry. A second small stream of water goes to the steam pressurizer to compensate for condensation at the slightly colder interface in the surge chamber. A very small stream is bled from the primary loop to the chemical processing plant where the non-gaseous fission products are removed and make-up fuel added. The reconstituted slurry, together with the balance of the recombined deuterium and oxygen that has been removed in the gas separator, reenters the system near the suction of the primary pumps.

One point of particular interest is that the rates of flow to the auxiliary systems are so small compared with the eighteen million pounds per hour rate of circulation in the primary system. Yet these auxiliary systems, which are indispensable to the successful and safe operation of the plant, contribute the major part of the complexity of the plant and a large fraction of its cost.

The principal philosophy underlying the first reference design was to make it conservative, to better delineate those areas where intensive development effort could have the most effect in reducing plant costs. The reactor inlet and outlet temperatures and the maximum slurry velocity were chosen from a very conservative interpretation of corrosion data available from Oak Ridge National Laboratory at the time studies began; as more experimental information is generated both there and in the PAR project, these design limits probably will be widened. The diameter of the spherical core was chosen quite large, probably larger than economic considerations will ultimately dictate. This was done for two reasons: first, to achieve a low power density at the core wall, which is conducive to long life; but equally important, to help determine problems and costs involved in pushing to the upper limit present-day technologies of large pressure vessel fabrication and handling. The decision to use two pairs of stop valves in each loop (a total of sixteen 20-inch valves in all) was made on much the same basis; the inclusion of these large valves, while facilitating certain maintenance operations, will significantly increase the plant capital cost, and only by a careful study of all the pros and cons can the question of their ultimate desirability be resolved. The secondary steam pressure of 400 psia was chosen after a very rough optimization of the problem. While this low pressure yields a relatively low thermal efficiency, there is little economic incentive in going to higher thermal efficiencies in a plant whose incremental fuel cost is extremely low.

As the work proceeded, not all choices could be made on the side of conservatism; in some cases, as in the problems to be encountered in the pumping of the slurry, favorable solutions from the experimental program were assumed. Optimism on this score has been largely justified.

Auxiliary sub-systems that complete the plant are shown in schematic form in Fig. 3. The deuterium and oxygen removed by the gas separator are reformed by catalytic action in the "external recombination system." The slurry-free heavy water so produced is used to wash the primary pump bearings, the pressurizer, entrainment separators and the like.

The xenon and krypton born in the fission process are held up on charcoal beds in the off-gas system until their radioactivity has decayed sufficiently so that, when diluted, they can be vented to the atmosphere. The off-gas system performs the same function for those gases generated in the chemical processing plant.

One small bleed stream is concentrated in the slurry letdown system and delivered to the chemical processing plant, which in Reference Design One is completely integrated with the power station. Because the build up of fission poisons in the primary plant occurs at a very slow rate, the maintenance schedule for the chemical processing plant can be quite independent of that of the primary plant.

The fuel-handling system in Fig. 3 comes into play when the plant is not in steady-state operation. Filling the primary loops on start up, draining them on shut down, and the more routine adjustments of fuel concentration are among the functions of this sub-system.

Development Program

This is, in general, the system under consideration; consider, then, the major problems and the programs to solve them. Without doubt, the most formidable problem in connection with the homogeneous reactor plant is that of maintenance of the components of the plant once it has been operated. Not only is the intense radioactivity of the fuel transported throughout most of the reactor plant, but those components in the primary system exposed to the delayed neutron emission become radioactive in depth, and no amount of flushing or cleaning will make them accessible for direct repair in the conventional sense.

This problem is shared by all reactor plants of the circulating fuel type, liquid metal as well as aqueous, and is the price paid for the important advantages in fuel costs these plants promise.

In the attack on maintenance problems, methods and devices of remote maintenance used at the reactor installations at Hanford and Arco are being studied. However, the special problems involved, including those of economics, require that additional ingenuity and imagination be brought to bear. A number of promising ideas have been advanced.

A second set of problems peculiar to the slurry plant is that associated with the pumping and handling of the slurry itself.

Fig. 4—Below, part of a 200 gpm, 580 degree F slurry circulating loop constructed of 3-inch stainless steel pipe. The canned motor-pump at right circulates the slurry through a heater section and then through corrosion test specimen holders, which can be removed at the end of the run. Photo at right shows the entire loop

The slurry particles are hard and quite abrasive. In stagnant regions the slurry tends to settle rapidly and under adverse circumstances may form a hard cake. At the outset of the development program, these and similar problems loomed largest on the horizon. Nevertheless, positive results have now been achieved. The attack is two-fold. In physical-chemistry laboratories, tests are conducted to provide measurements of particle sizes, settling rates, particle surface charges, redispersibility, and other rheological properties as affected by temperature, chemical additives, method of preparation and mechanical treatment. In engineering laboratories, the findings of the physical chemistry laboratories are tested in equipment more nearly approximating a real plant.

One of two almost identical corrosion test loops is shown in Fig. 4. In this and in a second similar loop, more than 5000 hours of pumping slurry at reactor temperatures have been accumulated. The longest continuous runs have been of 1000 hours duration and these have been terminated only for the removal of corrosion specimens. The loop has been shut down on a number of occasions, the slurry allowed to settle under both hot and cold conditions, and the pump restarted without difficulty. Insofar as corrosion and erosion are concerned, Oak Ridge results have been confirmed indicating that attack on stainless steels will not exceed 2 mils per year at velocities under 30 feet per second, provided a suitable chemical environment is maintained. These investigations are being extended to include other materials and experimental conditions.

The effects of high-intensity radiation on the slurry particles and on the behavior of the recombination catalyst is yet to be determined for circulating systems. An in-pile test loop of 30 gpm circulation rate is now being designed and built; this ultimately will be operated in the Westinghouse Testing Reactor to be constructed at Waltz Mill, Pennsylvania.

The third part of the development program concerns the design of plant components. These components must withstand high levels of radiation, must be essentially leak tight, yet easy to maintain by remote or semi-remote means, and in some cases are close to the upper limit of present-day technology in regard to size. With some components, an adequate initial attack consists in the study of modifications of existing designs. One example of this is the case of the primary pump. Large high-pressure hermetically sealed pumps have been developed for the circulation of high temperature water by the Westinghouse Atomic Equipment Department and have operated successfully for thousands of hours. The special problems attendant on the use of slurries in such pumps are being met and solved in the relatively small canned motor-pumps used in our corrosion-test loops. The solutions to these problems will be tested in larger scale at a later date.

A second example in this category of components is the large steam generator. The Westinghouse Steam Division has developed techniques for the automatic rolling and welding of small tubes into very thick tube sheets, and these techniques show great promise for application to the particular problems of the PAR project.

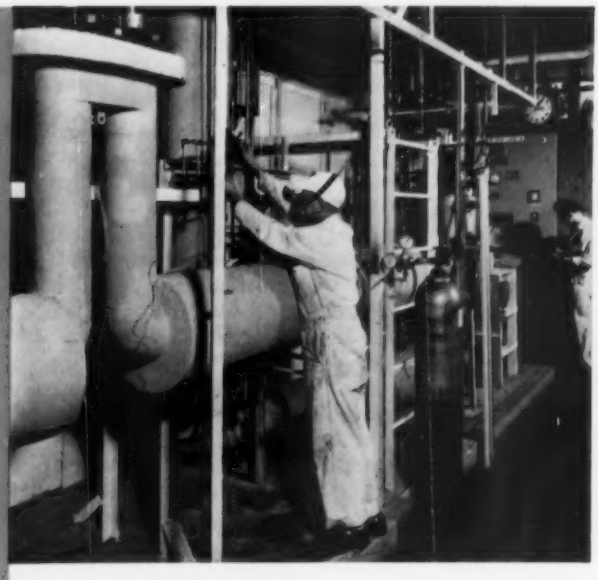
A second category of components is that in which almost no prior experience is available. One example of this is the high-head slurry make-up pump; a second is the slurry letdown device. Both are required to deliver a highly erosive suspension through a large pressure difference. To help solve these problems, two other high-pressure loops, smaller than that in Fig. 4, have been constructed and are being used to test several promising ideas.

Even if these ideas or others prove sound, the step from the successful operation of small loops to the design of a large plant is not easily made. To bridge this gap, an intermediate scale loop is being built. This loop will circulate slurry at 4000 gpm through 10-inch stainless steel pipe. It will be a complex of high- and low-pressure systems and will simulate in many respects the ultimate plant itself. The 4000-gpm loop will permit testing, at almost full scale, the ideas developed in the smaller loops. It will also enable testing of the remote maintenance techniques currently under consideration. This loop is expected to be in operation before the end of the first phase.

Progress to Date . . . . . .

Thorium-oxide slurries have been pumped in concentrations and at temperatures appropriate to the single-region reactor for more than 5000 hours. Significant inroads have been made on many of the major development problems. Although much remains to be done, solution of the technical problems associated with this plant within the established time scale appears feasible.

With regard to the economics of the plant, more caution is in order. While in the case of a breeder plant the bare fuel cost is essentially nil, the fixed charges are quite another matter. The cost analysis of Reference Design One is only now being completed but it is certain to be quite high. On the other hand, if present efforts in the direction of system simplification and the development of maintenance techniques are successful, a competitive power plant is in sight. ■



viewed from the opposite end. The slurry in the loop passes through the lower part of the pressurizer, then through a flow-measuring section, returning to the pump. In addition to the basic loop, there are many small lines and auxiliary devices for instrumentation, purge water, sampling, etc.

REFERENCES

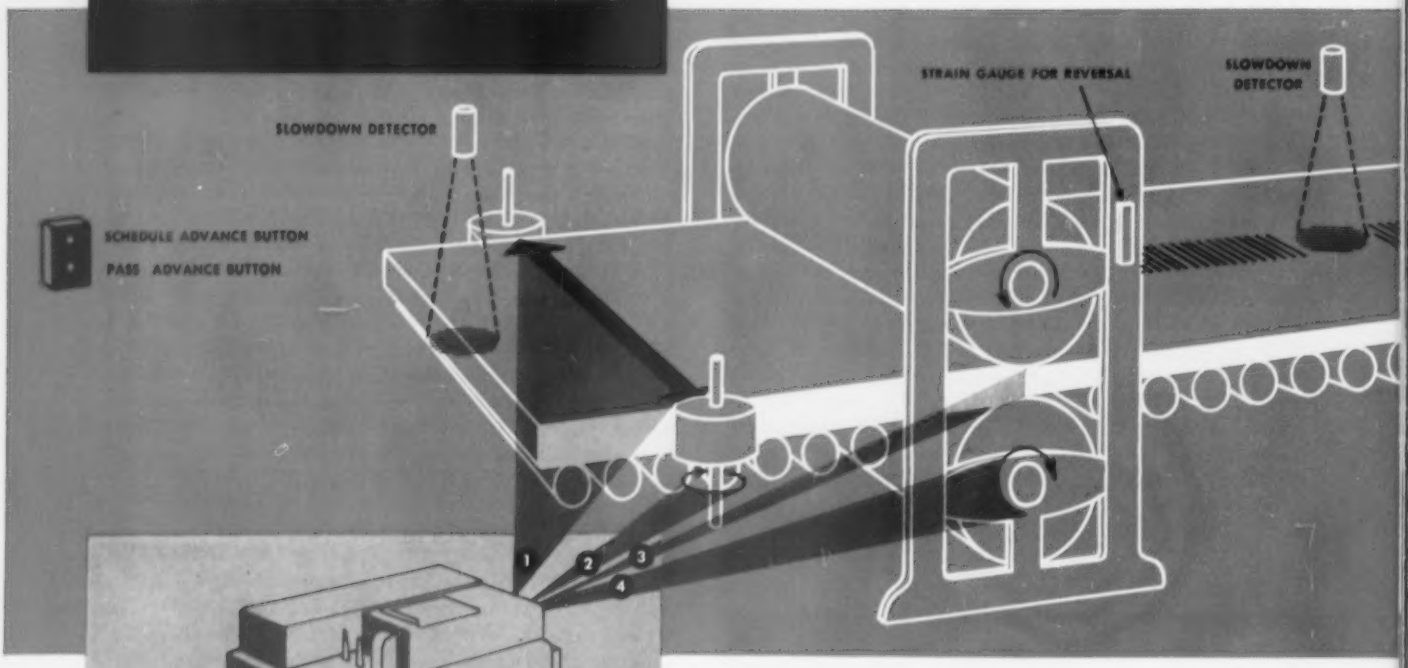
1 "Aqueous Homogeneous Reactors for Central Station Power," by R. B. Briggs, presented at Annual Meeting, Chicago, Ill., November 13–18, 1955 of the American Society of Mechanical Engineers.

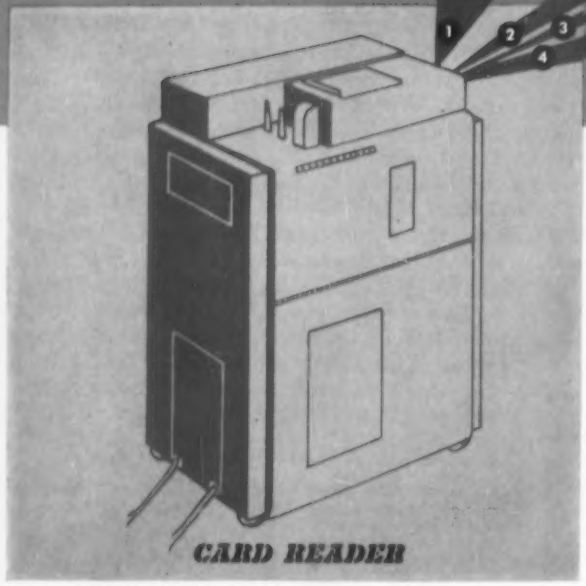
2 "Aqueous Homogeneous Power Reactors," by R. B. Briggs and J. A. Swartout, Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Geneva, Switzerland, August 1955, paper 496, Volume III, pp 175–187.

3 "The Homogeneous Reactor Test," by S. E. Beall and J. A. Swartout, Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Geneva, Switzerland, August 1955, paper 498, Volume III, pp 263–282.

CARD-PROGRAMMED CONTROL FOR REVERSING MILLS

ANDREW W. SMITH
Metal Working Section
Industry Engineering
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania





1 EDGER OPENING
2 EDGER SPEED
3 MILL OPENING
4 MILL SPEED

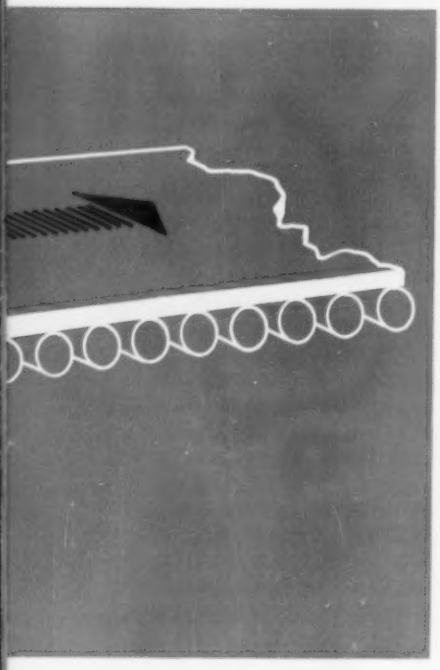
▪ Completely automatic operation of a reversing roughing mill will be possible with a new card-programmed control system. With this system, the operator can press a single button to initiate the complete rolling sequence for a given slab. The speed and roll openings of the vertical edger and the main rolls will be predetermined for a complete schedule by holes punched in a single IBM card. First installation of this new system, called Prodac (programmed digital automatic control), will be on the reversing mill at Jones & Laughlin's Aliquippa Works this year.

Of all rolling mills, the reversing rougher ahead of a continuous hot-strip mill is one of the most suitable for completely automatic operation. Since mills of this type can be fed with sheared hot slabs of relatively uniform quality, a given strip size can be rolled using a definite set of reductions. Such variables as slab temperature and type of steel can be taken into account by using two or three schedules to make a particular strip size from a given incoming slab. For example, typical rolling schedules might call for five passes for hot or soft metal, seven passes for metal of

average hardness, and nine passes for the cold or hard metal.

This universal reversing roughing mill feeds a six-stand continuous hot-strip mill. Slabs will be brought directly from the blooming mill or the reheating furnaces and passed through a separate vertical scale-breaking edger. The rolls of this edger are each driven by a 500-hp, 360-rpm squirrel-cage motor and are located approximately 30 feet in front of the horizontal mill.

Each of the main horizontal rolls is 44 inches in diameter and 44 inches wide and is driven by two 3000-hp, 40/100-rpm motors arranged to form a 6000-hp twin motor. The mill itself has attached edger rolls; each of these rolls is 24 inches in diameter and is driven by a 375-hp, 360/450-rpm, 230-volt mill motor, which is operated up to 460 volts. This attached edger is located 6 feet from the center line of the main rolls.



The card-programming system makes the mill operation completely automatic. The IBM card inserted in the reader tells the horizontal and vertical rolls the speed and roll opening for each pass. Hot metal detectors initiate the slowdown when the tail end of the strip approaches the mill and a strain gauge in the housing stops the mill and signals for the next roll opening and the next pass.

The horizontal mill screw downs are driven by two 75-hp, 515-rpm mill motors and the attached edger rolls are adjusted with two 50-hp, 550-rpm mill motors.

To initiate a rolling schedule, the operator places a stack of IBM cards in a card reader (see sketch), in the order in which they are to be used. When the schedule-advance button is pressed, the first card passes through the machine in less than a second and all information for that particular schedule is stored in transistor-type memory devices. If several slabs are to be rolled for a given schedule, this information can be used over and over to roll any number of slabs.

Prepared beforehand, IBM cards will be available for nearly every slab and strip size and for each grade of steel. These cards are prepunched to call for the optimum drafts and speeds that give a uniform product at as high a production rate as possible.

A single IBM card includes all information required for a given schedule, and controls: (1) mill screw-down opening, from 0 to 14 inches in 1/32-inch increments; (2) edger adjustment opening, from 6 to 44 inches in 1/16-inch increments; (3) mill speed, at 115, 300, 440, 715, 880, or 1100 fpm; and (4) edger speed, which is matched to mill speed, but from 0 to 40 percent slower to take care of draft in the horizontal mill. Eight five-percent steps are available. Also included on each card is a notation to indicate the last pass.

To make mill operation completely automatic, a detector that responds to strip radiation is located on each side of the mill. Each of these detectors is approximately 8 feet from the center line of the mill and initiates the slowdown when the tail end of the strip approaches the mill. A strain gauge, located on the mill housing, detects the instant the strip leaves the mill for fast repositioning of the rolls and re-entering for the next pass. This strain gauge is better able to detect the end of a pass than an operator, since the edging rolls obstruct his view of the horizontal rolls.

After the information for a particular schedule has been read and stored in the transistor elements, the mill is ready for the slab. As the slab approaches the mill, the operator pushes the pass-advance button to initiate a sequence of operations. First, the horizontal and vertical roll openings are preset. Next, the mill is adjusted to run in the forward direction at the proper speed. When the tail end of the strip is about 8 feet from the mill, as seen by the detector, slowdown is initiated to give a predetermined mill speed of about 300 feet per minute at the time the tail end leaves the horizontal rolls. At the same time that mill slowdown is initiated, the delivery-table control calls for zero speed so that the strip will be delivered onto a dead table. When the steel leaves the horizontal rolls as detected by the strain gauge in the mill housing, the mill is automatically brought to rest and the rolls are automatically repositioned for the second pass. When the rolls are properly positioned, the mill runs in the reverse direction at the correct speed.

The cycle of operation in the reverse direction is the same as that for the forward direction with one exception. When mill slowdown is initiated, the delivery table is not brought to rest but continues to run at a slow speed until the tail end of the strip has cleared the vertical rolls, as indicated by the slowdown detector on the edger side of the mill.

In operation, the schedules will probably be arranged to make a reduction with the edging rolls in the forward direction only. The card will be punched for even-numbered passes to open the edging rolls approximately four inches from the previous setting to allow the proper clearance between the strip and the edging rolls. The edging roll adjustment can be initiated at the same time that horizontal roll adjustment occurs, when the strip leaves the horizontal rolls. This is true even for the reverse passes, since when the table is running at low speed it will be able to carry the strip clear of the edging rolls before the vertical rolls travel the 3- or 4-inch clearance space.

At the beginning of the last pass, a light in the operator's station at the crop shear will alert him to be ready to receive the strip for entry into the finishing mill. After the last pass, the finishing-mill approach tables will be stopped unless the operator at the crop shear is ready for the strip and has his table master switch in the forward direction.

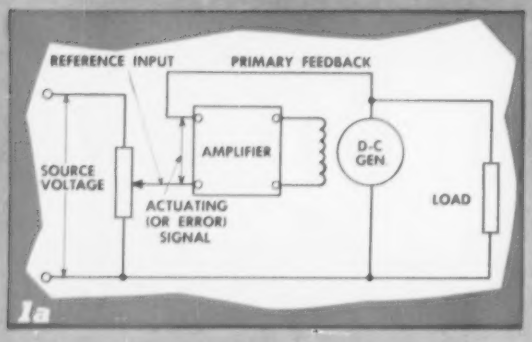
The control system includes the equipment necessary to relieve the operator of many operations. The sequence of operation for the rolling cycle can be adjusted to approach the abilities of the best operator. With proper care in preparing cards and in making original adjustment of the mill, a consistently high production rate can be maintained, particularly if the production schedule is well organized. ■

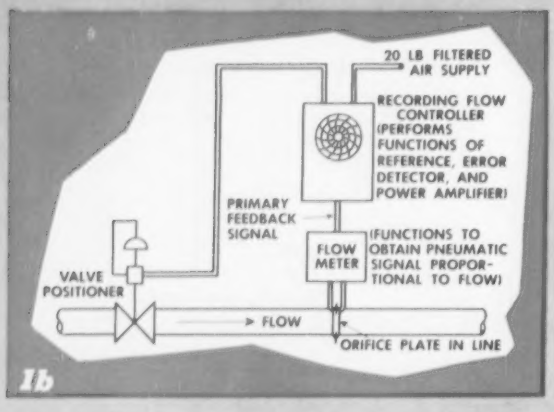
FEEDBACK CONTROL PRINCIPLES for INDUSTRIAL DRIVES

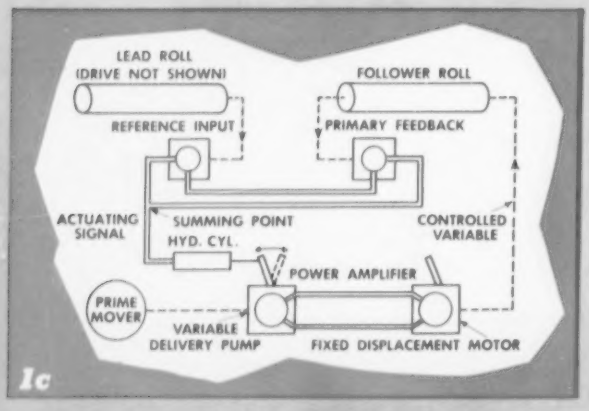
C. G. HELMICK
Industry Engineering Department
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

■ The hiss and roar of a giant, white-hot ingot being rolled in a blooming mill is ample testimony to the tremendous power harnessed to this task; in contrast, the contented purr of a machine spinning delicate man-made fibers attests to the gentle action with which this process is controlled. Behind this dramatic contrast is a basic and fundamental similarity; both are examples of the same principles of feedback control.

In any feedback regulator system, the output quantity to be regulated is compared to an input reference, which is proportional to the desired output, and the difference is kept as small as possible—ideally zero. This is accomplished by measuring both input and output, comparing them, and using the difference to control the output. The system components can be electrical, hydraulic, mechanical, pneumatic, or any combination of these. In addition, modern process control makes use of any number of transducers, devices that convert some process variable to a control signal for regulating purposes. Although the individual blocks in a diagram can assume an infinite number of physical forms, their function in a feedback control system follows similar principles.




20 LB FILTERED AIR SUPPLY
RECORDING FLOW CONTROLLER (PERFORMS FUNCTIONS OF REFERENCE, ERROR DETECTOR, AND POWER AMPLIFIER)
PRIMARY FEEDBACK SIGNAL
FLOW METER
(FUNCTIONS TO OBTAIN PNEUMATIC SIGNAL PROPORTIONAL TO FLOW)
VALVE POSITIONER
FLOW
ORIFICE PLATE IN LINE
1b



Industrial Drives

Industrial drives utilize the same principles as other regulating systems, but have some special requirements of their own. The power level involved usually sets the industrial drive clearly apart from its counterpart—the instrument drive. A positioning servo for an analog computer, or a self-balancing potentiometer for recording instruments uses low-power components of special design to get characteristics tailored to the application. On the other hand, the power ratings of most industrial drives are so large that design of these machines for ideal control characteristics is impractical. For example, a 50-hp squirrel-cage servomotor designed with linear control characteristics would have to be prohibitively large to dissipate the high resulting rotor losses. Economic factors must also be considered; a servomotor with an efficiency of 10 percent may be entirely practical for a sub-fractional-horsepower instrument drive, but could hardly be considered for 100-hp screwdown motors on a rolling mill.

Hence, special features of small drive components can seldom be duplicated at industrial power levels. As a compromise, near-standard machines are used where possible, and the feedback controller recovers the attendant loss in performance. Fortunately, this usually can be accomplished, but not without a thorough examination of the entire system. For high-performance systems, standard elements may have to be modified to reduce time delays, improve machine gains, or reduce saturation effects. From a cost standpoint this is nearly always less expensive than designing a new machine with special characteristics. The ultimate consideration is drive performance,

Fig. 1—Typical example of industrial regulating systems using feedback control are (**a**) an electric regulated system for holding constant generator voltage, (**b**) a pneumatic regulated system for holding constant flow rate in a pipe line, and (**c**) a hydraulic regulated system for speed matching of two rolls.

and if this can be met with conventional equipment, it is the practical solution.

Performance

From the operating viewpoint, performance is the most important single factor. Will the mill roll acceptable products with a given drive? Does a production run of nylon yarn have sufficiently uniform denier to permit successful dyeing? If not, what adjustments must be made.

In general, the quality of performance of a regulated system can be described by three factors: (1) steady-state accuracy, (2) system speed of response, and (3) system damping, or rate of decay of oscillations. The first term describes how closely the controlled variable normally can be held in relation to the command input, which is certainly an important consideration; speed-of-response describes how *fast* normal conditions can be restored to a system after a disturbance; and system damping describes the manner or *quality* with which normal conditions are restored after the disturbance. Actually, all three performance factors are closely interrelated.

Steady-State Accuracy

The normal accuracy with which system output follows the command input signal depends upon *system amplification*. Technically speaking, this is the open-loop amplification or gain, which can be found in a simple system by taking the product of the gains of all components in the loop, including the feedback loop. The term "open-loop" derives from the fact that if the control loop is opened at any point, the system amplification can be found by inserting a test signal at one point of the break and measuring the signal that results at the other side of the break. The ratio of these two signals is the system (or open-loop) amplification.

For more complex systems with minor loops, parallel elements, feed-forward loops, etc., methods are available to reduce such systems to an equivalent series block diagram. The product of the gains of the simplified components so obtained is system amplification.

Adjustment for system amplification is most readily made by adjusting amplifier gain. In practical industrial systems, gains of exciters, generators, or tachometers are relatively inflexible once designed. Consequently, the amplifier is provided with excessive gain, so that a simple adjustment of an input-sensitivity potentiometer produces the desired system gain.

While open-loop gain is the quantity most easily adjusted, certain feedback methods can increase or decrease the effect on performance. While the loop remains open, amplification is normally high, say 10 to 500. As soon as the loop is closed, however, the "through-gain" or "closed-loop" gain can be shown to approach unity, as indicated by the equation:

$$\frac{\text{Output (per unit)}}{\text{Input (per unit)}} = \frac{C}{R} = \frac{A}{1+A} \qquad (1)$$

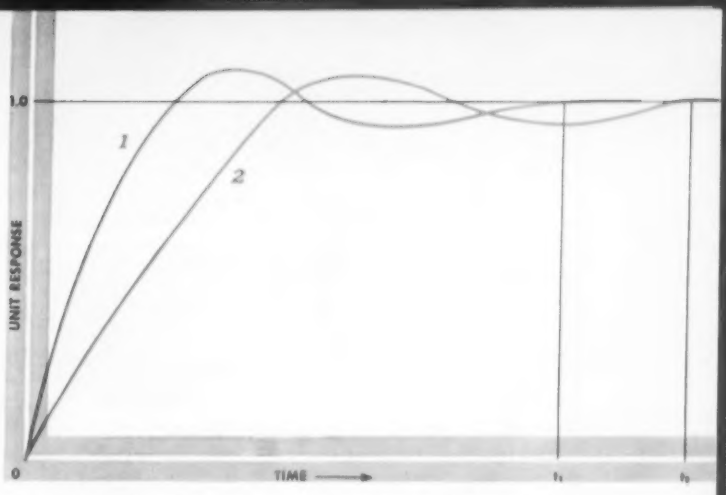


Fig. 3—Typical system response to a step-input disturbance.

The desired value of C/R, which is the ratio of output to input (both expressed in per-unit quantities), will be close to unity since normally the purpose of the regulator is to provide a one-to-one relationship. A large value of open-loop gain A will cause C/R to approach unity. Steady-state error is based upon this idea, by measuring how much error exists between C/R and unity. Hence:

$$\text{Error} = 1 - \frac{C}{R} = 1 - \frac{A}{1+A} = \frac{1}{1+A} \qquad (2)$$

A steady-state error always exists unless amplification can be made infinitely large. This error is the necessary actuating signal to run the system from no-load to full-load output. Some systems, however, utilize *positive* feedback, or self-energization, to achieve the same effect as infinite steady-state gain. These systems actually operate with negligible steady-state error. While the steady-state gain is made very large by the use of self-energization, this has little or no effect on the gain during transients. More will be said about this later.

Speed of Response

System performance consists of more than the steady-state condition. A system is subjected to various disturbances from time to time, and must return to normal operation rapidly and effectively. These disturbances can be caused by load changes, power-supply variations, changing machine characteristics, ambient conditions, or many other factors.

The most widely used method of measuring response to disturbances is to apply a step change to the system and observe the output variation. Such a test is relatively easy to perform and represents a much more severe disturbance than the drive is likely to encounter in service. Good response under these

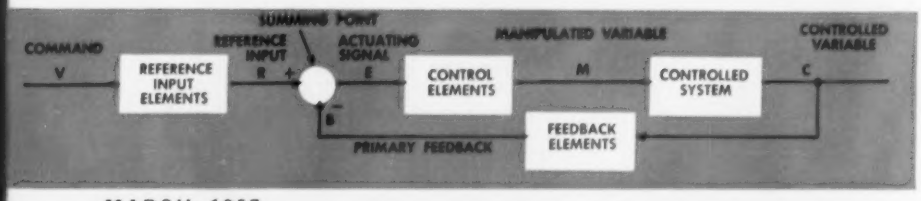


Fig. 2—Basic components in any feedback control system are shown in this simplified block diagram.

worst conditions assures adequate field performance.

Discussion of response time in an exact quantitative manner is difficult because of the many aspects of system response to consider. Several significant aspects of transient response include: (1) time required to first reach a specific percentage of the final value; (2) time required to reach the first peak overshoot; and (3) time required for the transient to decay to a specific value. The most useful approach, short of drawing the response curve, is to speak *qualitatively*. Thus, in Fig. 3, curve 1 has a faster response than curve 2. In the adjustment of a regulating system, the fastest response practicable is usually desirable, but again, this is a relative concept.

The speed of response of any system usually depends on three factors: *system amplification*, the *time delays* of the elements comprising the system, and the nature of the *disturbance* to which the system responds. These factors are interrelated closely. For example, system output will follow input more closely for a slow moving change than for a sudden change. This was the reason mentioned previously for using a step change as a good field test for overall performance. Also, other things being equal, a system with a large delay will have a slower response than one with a small delay.

The control designer relates these factors by a block diagram (see Fig. 4) containing the terms A, T, and S. The value of A is a constant and is the steady-state value of open-loop amplification previously discussed. T is also a constant, and is the time delay of the element involved. S is a variable quantity (the LaPlace operator), which includes the effect of the disturbance function. For a sudden step change, S is very large. For steady state, or *no* change, $S = O$.

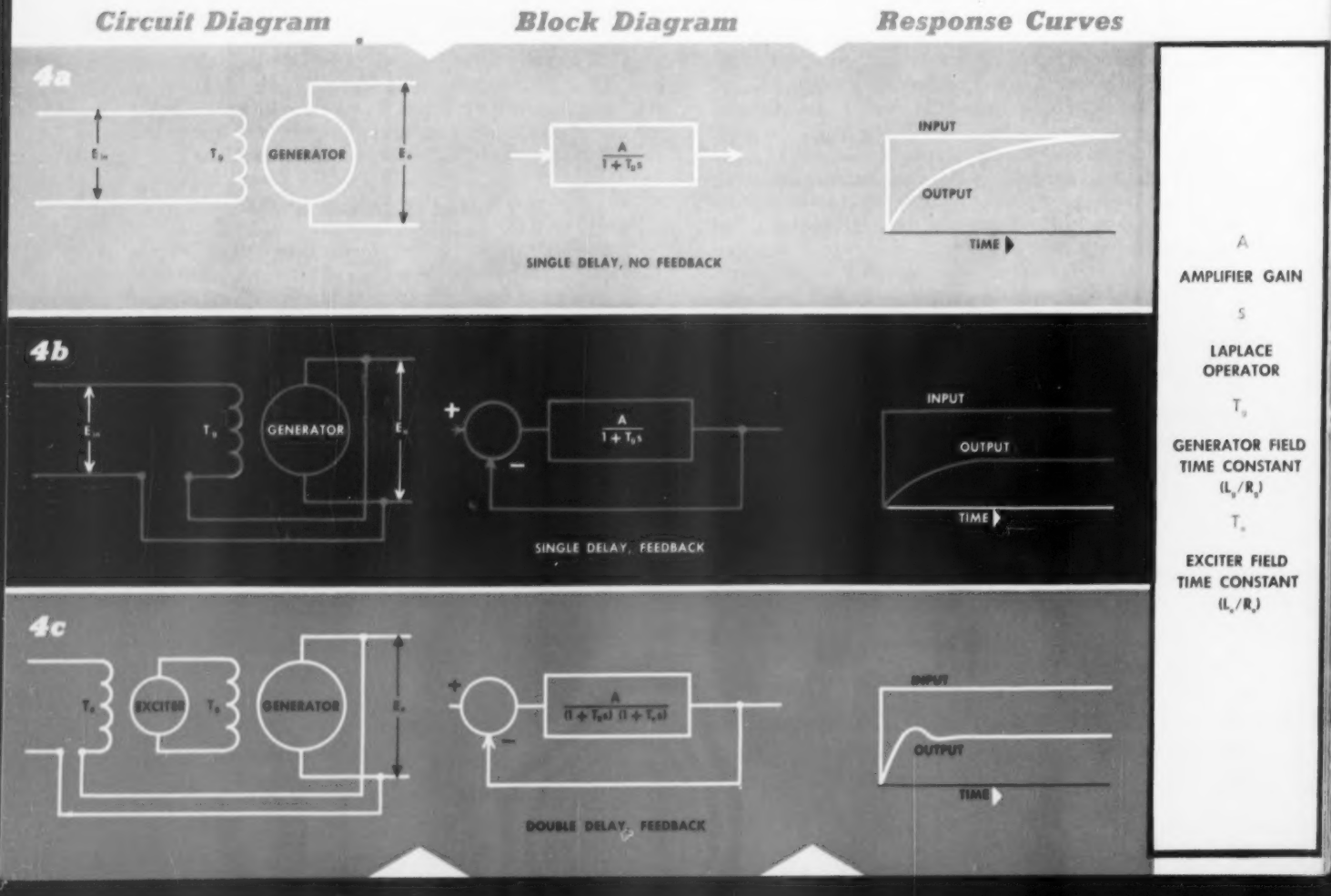
Without going into the mathematical analysis of feedback control systems, a high speed of response generally requires high amplification. A maximum permissible value of gain exists, however, above which the system will be unstable. A practical method of installation adjustment is to increase the gain as much as possible while still avoiding a hunting or oscillating condition. This value of gain is then reduced by a small amount to provide a margin for stable operation.

The oscillating condition results from the interaction of the component time delays when system gain becomes too high for stable operation. In all but the simplest cases, this interrelation is not obvious, and few generalizations can be made. In a simple single-delay system, response time is proportional to the single time delay involved. Any faster response time is achieved by reducing the effect of the single time delay. This can be done by increasing the system gain, reducing the time delay directly, or by forcing (discussed later). For example, if the delay is an electrical field delay expressed by $T = L/R$, it can be reduced directly by increasing the resistance, R. However, the applied voltage must be increased to overcome the added resistance drop. A practical solution often used is to reconnect a 230-volt field into two parallel 115-volt fields, with sufficient external resistance to operate from the 230-volt supply.

For two-delay systems, the generalized response is shown in Fig. 6 for different values of system damping. Note that in all cases the time to reach the peak overshoot appears to be about

TIME DELAYS

Fig. 4—The effect of time delays is shown for a step input to three fundamental control systems: (**a**) simple single-delay system, such as a d-c generator with no feedback; (**b**) single-delay system with feedback, such as a d-c generator with negative feedback to the generator field, and (**c**) two-delay system with feedback, such as a d-c generator with negative feedback to the exciter field.



3 or 4 times the natural period expressed as *response time*. Response time can be improved by increasing system gain, but this also results in less damping and greater overshooting. Although a generalized response can be made for two-delay systems, most practical regulating systems involve a higher number of delay elements, thereby making the analysis more difficult. Some generalization can be made for the higher order systems; for example, time delays should be as widely separated as possible. In doing this, reduction of the small delay will usually be more effective than increasing a large delay.

Damping

Response time has little significance unless system damping is also considered. Damping from the performance standpoint describes the *quality* of response; in other words, how much oscillation takes place, and how fast does it disappear? System damping is often measured in terms of "percent decay per cycle." This figure is helpful since it evaluates the effect of damping regardless of response time. It is not sufficient to speak of decay *time* alone, because such a term could be the same for a fast system or a slow system, whereas the effective damping may be much different.

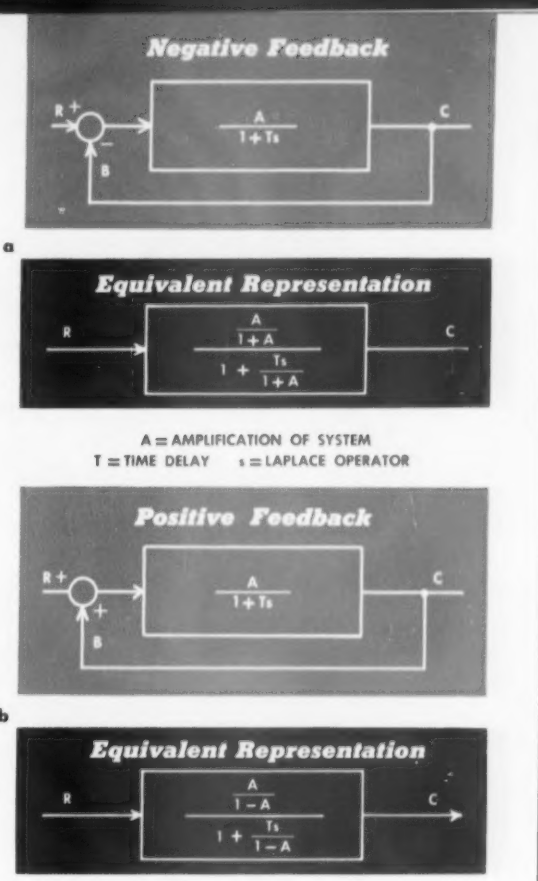
In many industrial systems some overshooting is entirely satisfactory as long as the peak overshoot and settling-out time are not excessive. A paper-machine reel drive, for example, may need only 80 percent damping, since slight oscillation will not alter the quality of the paper. On the other hand, at the wet end of the machine where the paper is formed, oscillations can produce variations in the paper thickness. Here, system damping may have to be 95 or 100 percent per cycle.

To understand the factors that influence system damping, its basic nature must be considered. In the fundamental system previously considered, the feedback controller sees only the relation between input and output signals. If the corrective action is proportional only to the difference of input and output, the system will probably overshoot the mark in responding to a disturbance. This is particularly true for systems with high inertia, where accelerating and decelerating torques can be as great or greater than the load torque. When such a system accelerates toward a new reference point, there is no signal to slow down until overshoot has already occurred.

Rate Damping or Anti-hunt

If the error signal is modified by a second signal proportional to output *rate of change*, overshooting can be reduced or virtually eliminated. The rate signal is subtracted from the normal error signal, with the net difference used to effect the corrective action. Then with a large difference between input and output, the normal error signal is large compared to the rate signal, and normal corrective action ensues. As the system first accelerates toward the desired operating point, the error signal decreases, and the rate signal increases. Thus the rate signal reduces the corrective effort even before overshoot occurs. In an ideal system, both normal error signal and rate signal disappear as the desired value is attained, and no overshoot occurs. In a practical system such performance can be closely attained.

This type of damping is termed *rate* damping, since it depends on modifying the normal error signal with a signal proportional to the rate of change of the output signal. The terms *damping*, *anti-hunt*, and *feedback* are often applied to the same fundamental concept of opposing the main actuating signal with another to caution that the system is moving too fast.



FEEDBACK PRINCIPLES

Fig. 5—The primary feedback signal in a closed-loop system (**a**) is **negative**, in that it opposes the reference signal. The effect on system performance is twofold, since both gain and time delay are reduced: Open-loop amplification *A* is reduced to $(A/1+A)$, or approximately unity; main time delay is reduced by the factor $1/(A+1)$. Generally, negative feedback reduces gain, but improves stability by reducing the effective main time delay.

Positive feedback, such as self-energization, has an opposite effect: System gain and effective time delay are both **increased**. This is seen from the equations for the equivalent circuit in (**b**). As *A* approaches unity, time delay *T* approaches infinity. Thus, the self-energizing response is sluggish, and has little effect during transients.

Sometimes damping circuits are confined to components within the system, such as a two-stage amplifier with inter-stage rate feedback opposing the main signal. In this case, rate feedback tends to stabilize the amplifier. Other examples include feedback rate signals of generator voltage or motor current to indicate that some limiting portion of the system is changing too fast for safe and stable operation. The type and location of these rate circuits is an important part of system design.

A rate signal can be obtained in several ways. A tachometer generator produces a signal voltage proportional to the rate of change of shaft angle. A damping transformer produces a secondary voltage proportional to the rate of change of primary voltage. Resistance-capacitor differentiator circuits produce an output voltage very nearly proportional to the rate of change of the input voltage. These are several electrical methods of obtaining damping. Mechanical damping is also possible by the use of eddy-current devices coupled to the

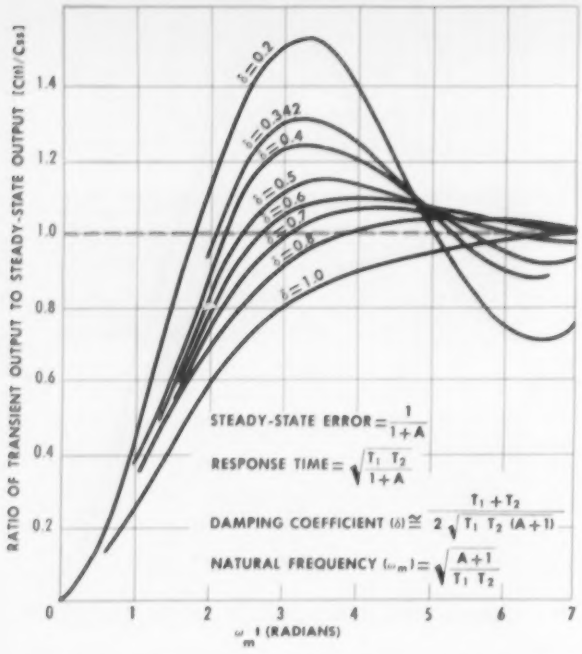


Fig. 6—Generalized response of two-delay feedback control system.

drive motor shaft. Such a device produces a counter-torque proportional to speed. While this method is often used for instrument servos, it is seldom practical for industrial drives. The power that must be dissipated is much greater than for the instrument drive, and the main drive motor must be larger to overcome this loss.

Many simple systems have sufficient damping inherent in the machines to provide stable operation without resorting to special damping circuits. More complicated systems and high-gain systems need damping because, in general, high gain tends to make a system less stable. Systems requiring exceptional transient performance must be well stabilized since heavy forcing is usually employed to get fast response.

Forcing

The object of *field forcing* is to obtain very fast transient response by minimizing the effects of normal time delays. This is accomplished by calling for a transient output that is higher than needed for the ultimate steady-state condition. If, for example, normal field voltage is applied to a d-c generator, the generator field current and output voltage rise on a simple exponential curve determined by the field time constant. If double the normal field voltage is applied, the field current builds up towards twice normal, according to the same time constant. Consequently, field current reaches its *rated* value much sooner because of this field forcing. It is evident that some means is required to catch the generator voltage before it becomes too high; this is the purpose of the differential field across the generator terminals, which opposes the main field as generator voltage increases. The result is a rise of field current intermediate to the two curves, but with a distinct improvement in response time, as shown in Fig. 8. The anti-hunt in this case is a direct feedback opposing the main actuating signal, rather than a rate feedback. The fundamental effect is similar, however, in that the anti-hunt signal acts to prevent dangerous or undesirable conditions from arising.

Summary

In discussing control principles underlying operation of the largest to the smallest regulated drives, emphasis has been placed on basic similarities. The form, size and shape, as well as the quantity to be regulated, may be drastically different from one system to the next. No attempt has been made to describe all the different types of regulators in common use, such as voltage, current, speed, tension, position, or power regulators, to mention a few. In analyzing each of these systems, however, it is interesting to note that each system can be reduced to a block diagram, which represents components of the overall system.

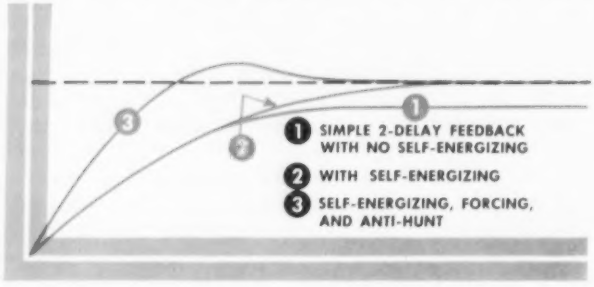
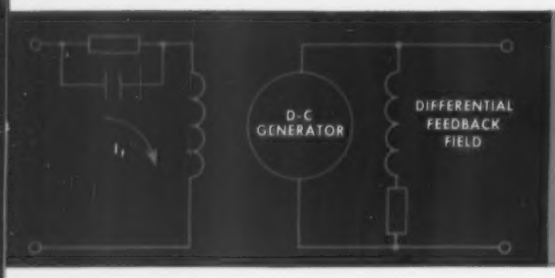


Fig. 7—These typical response curves show the effect of self-energization, which improves steady-state performance, and forcing and anti-hunt, which improve transient performance.

Various combinations of positive and negative feedback, including special phase-shifting elements, all help the designer modify component time delays to get good, stabilized operation. However, his problem is further complicated by the fact that component gain and time delay values can change with operating conditions. For example, a d-c generator operating on the lower portion of its saturation curve has higher gain and higher time delay than when operating in the saturated region. The same is true for a d-c motor, with the added complication that the *mechanical* time delay also changes nonlinearly. Consequently, a system must be designed to give satisfactory performance under the worst possible condition of operation. ■



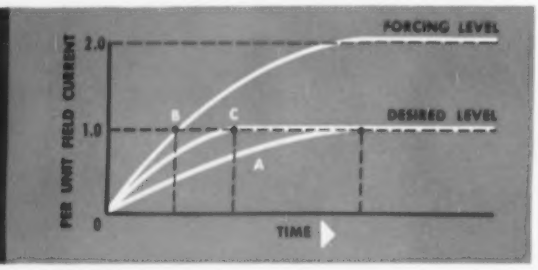


Fig. 8—Field forcing minimizes the effect of time delay in a d-c generator. Effect of the differential field in opposing main field at high generator voltages is illustrated by curve C, a response intermediate to response curve A with no field forcing, and curve B at field-forcing level.

TRANSFORMER TEST CENTER

▪ As power-transformer ratings continue to scramble up the kva scale, development, manufacturing, and testing facilities must follow the same pattern. Power transformers cannot be simply scaled up to achieve a higher rating; each giant new unit must be individually designed, developed, and tested. To keep pace with these demands, productive capacity for power transformers has recently been upped more than 30 percent. Accompanying this increased capacity is a complete new test center, equipped to make commercial and development tests on the largest units forecast for the next ten years. Considering the kva ratings and physical size of these units, this is no small order.

Basically the new test center consists of four related parts—a commercial test floor, a huge anechoic vault, a versatile high-voltage development laboratory, and a special room for measuring radio-influence voltages. The equipment available is capable of making complete tests—including power-loss measurements, temperature runs, sound-level measurements, and impulse tests—on completely assembled units rated in excess of 500 000 kva.

Anechoic Vault—The possible sources of sound from a transformer are several. The primary source is magnetostriction; alternating flux in the core results in a cyclic change in length of the laminations, setting up sound waves. But auxiliary apparatus—fans, pumps, and tap changers—also can be important sound sources. To add to these, another tough problem is that various parts of the transformer can be resonant, and under such conditions will radiate much more than their normal amount of sound.

The new anechoic vault will be used to test production units and to study the causes of transformer noise, thus enabling construction of even quieter units. This vault is a large concrete box enclosure about 70 feet long, 55 feet wide, and 60 feet high. Massive exterior construction was necessary to shield out shop noises, since this vault opens onto the commercial test aisle. Inside construction, from concrete inward, consists of a nine-inch air space enclosing a two-inch blanket of fiber glass and aluminum foil; heavy plywood mounted on timber framing; and an inner surface, or anechoic lining, consisting of fiber glass wedges (see photo, next page.). The whole vault is isolated from the main building structure. The anechoic vault also has a metal shielding that enables radio-influence testing of equipment in the chamber.

Transformers to be tested are rolled in on rails. The vault is large enough to accommodate transformers with a width of 30 feet and 40 feet high, weighing up to 400 tons.

Many different types of tests can be performed in the new chamber. For example, typical spectrums of sound from a good quiet transformer can be recorded; then when other transformers are studied, abnormal variations from this spectrum can be detected, and further tests made to ascertain the cause and necessary corrective measures. In addition to this type of test, many special investigations can be made. For example, one possibility for reduction of sound is to use sound-absorbing material inside an oil-filled transformer. Preliminary investigations indicate that if the right materials can be found, the noise level of a transformer might be reduced as much as ten decibels. Many other possibilities will be explored in this new vault.

High-Voltage Laboratory—The high-voltage development laboratory is used primarily to test new insulation structures of various materials and configurations. Included among the test equipment are three surge generators—one of 5200-kv, another of 4000-kv, and a third of 600-kv capacity. Other apparatus includes a 1050-kv, three-unit cascade transformer and a 200-centimeter sphere gap. This equipment is used both in commercial and development testing of power transformers.

Radio-Influence Facilities—Two facilities can be used for radio-influence measurements. As mentioned, the sound laboratory is shielded to permit measurements; also a specially designed room is also available. All circuits to the sound room and the RI room are filtered to prevent passage of radio frequencies through these circuits.

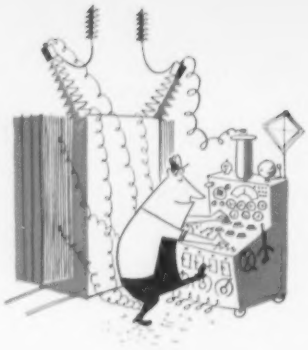
Measurement of radio-influence voltages are important for several reasons. For one, they affect radio and television reception, and are thus an annoyance. Because they are generated by ionization, these voltages also offer a means of determining the degree of ionization in electrical equipment. And third, high radio-influence levels can be used to direct homing devices, and are obviously undesirable from the standpoint of national security. With these two new testing rooms, present insulating structures can be tested and new ones developed.

Commercial Testing—Commercial testing equipment forms the fourth part of the new test center. Transformers to be tested are moved into the testing aisle by crane and lowered onto rails. Two different transformers can be tested simultaneously, one at each of two test stations. The units undergo a series of 60-cycle tests, including loss and power-factor measurement, then are impulse tested using the 4000-kv surge generator. Applied potential tests on the high-voltage windings are then conducted using the 1050-kv cascade transformer. Induced tests are then conducted at 120 cycles. Other tests are also conducted while the unit is in the aisle, including those on auxiliaries; also these small units are filled with oil under vacuum at the test stations.

Larger transformers are partially assembled on the main assembly floor, lowered onto buggies in the testing aisle, and assembly is completed, after which commercial testing is finished.

These and other facilities in the new transformer test center provide a complete installation for testing all transformers anticipated for the next ten years, plus development facilities for the transformers of the longer range future. Key features of the new center are illustrated on the following two pages. ▪

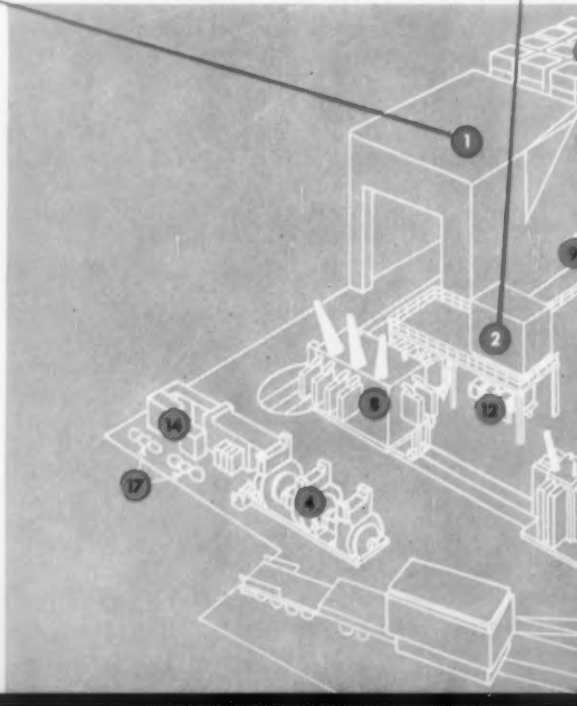
Complete sound measurements can be made on transformers rated more than 500 000 kva and weighing more than 400 tons in this new anechoic vault. Designed for an ambient noise level of less than 30 decibels, this huge chamber is 70 feet long, 55 feet wide, and 60 feet high, and has walls nearly five feet thick. This room is also shielded to permit radio-influence measurements.

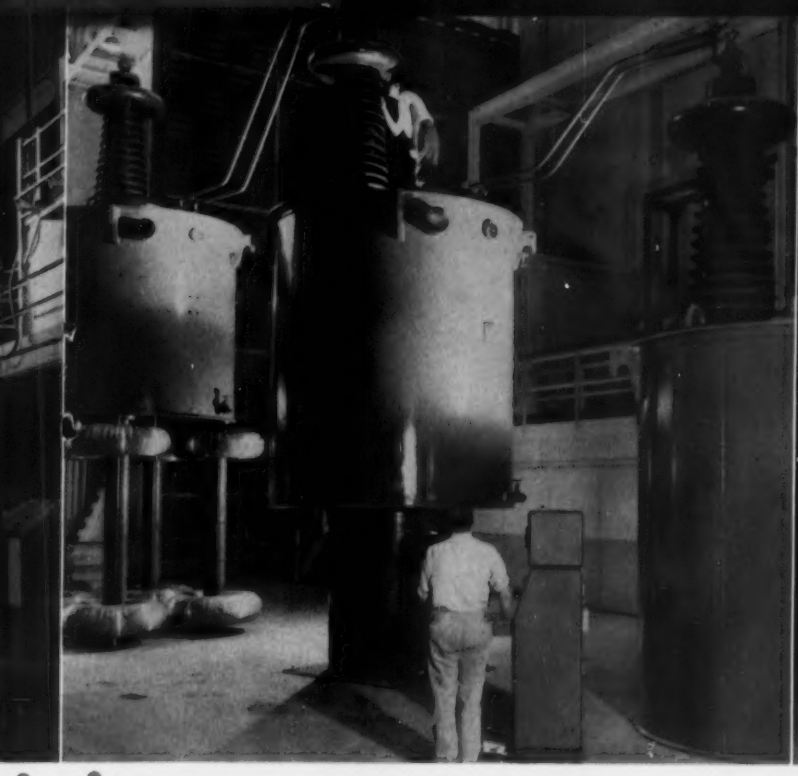


Commercial test aisle of the new test center, viewed from the adjacent assembly aisle. At right is one of the two test booths, under which are power-regulating transformers. At far left is part of the 20 000-kva motor-generator set, and beyond that the master switchgear. Light-colored walls and 1000-watt fluorescent-mercury lamps provide an average illumination of 35 foot-candles.

TRANSFORMER TEST CENTER

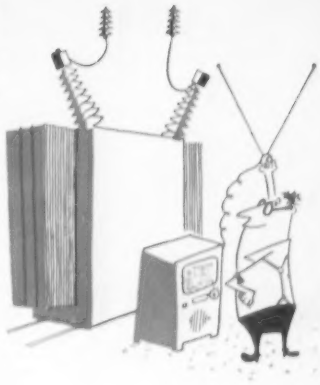
1. Anechoic vault
2. Test booths
3. Radio influence room
4. 20 000-kv motor-generator set
5. 5200-kv surge generator
6. 4000-kv surge generator
7. 1050-kv 3-unit cascade transformer
8. Transformers to be tested

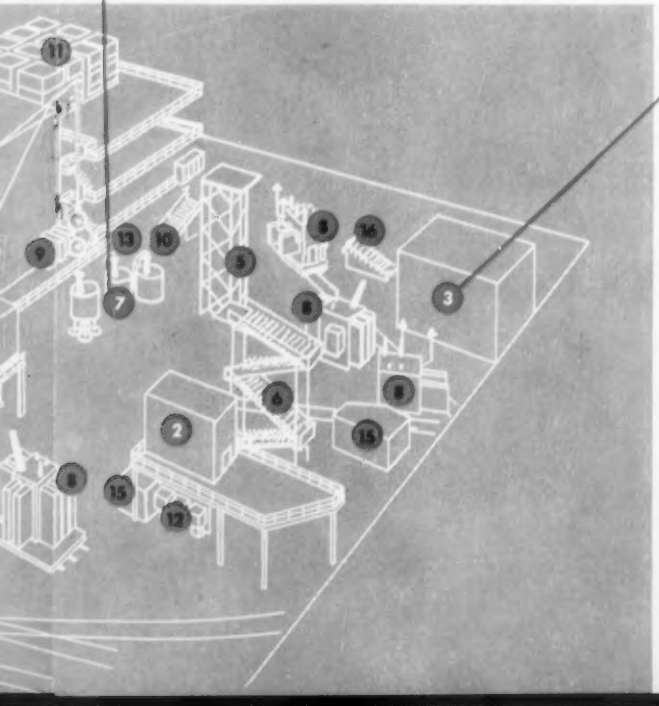




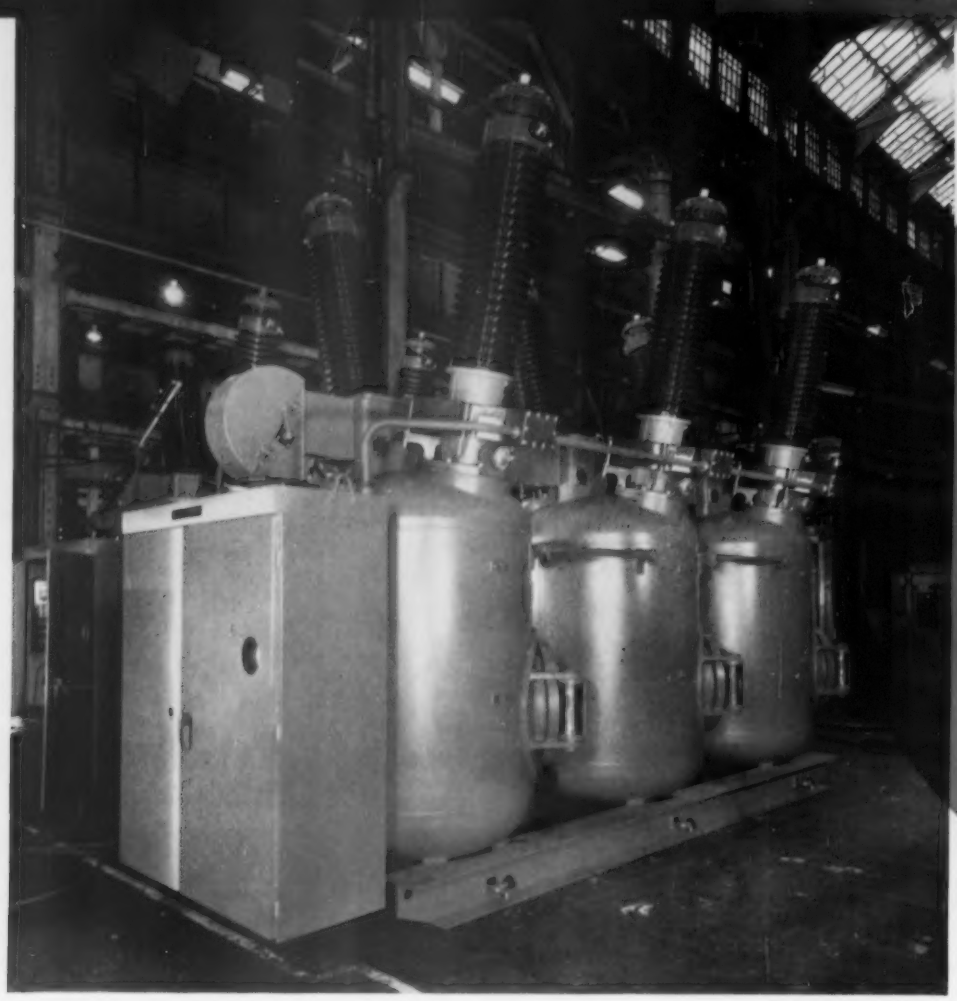
This cascade transformer bank in the new test center provides 1 050 000 volts at 60 cycles for both development and commercial tests. The metal doughnuts at the base of the tallest unit effectively increase the distance between the tank and ground by reducing the high surface voltage gradients. The 150-ton door of the anechoic vault can be seen in the background of this photo.

Radio-influence room will be used primarily to investigate and develop better insulation structures. In photo, an engineer is measuring RI voltages radiated from the transformer on test and picked up by the loop antenna. Another important function of the room will be to aid in standardizing and improving RI voltage measuring techniques. Testing transformer energizes unit on test.





1. Power filters for sound room
10. 600-kv surge generator
11. Capacitor banks
12. Power regulating transformers
13. 200-cm sphere gap
14. Master switchgear
15. Control rooms for surge generators
16. 180 000-ampere current generator
17. Auxiliary power motor-generator sets



New 3-pole, 138-kv grounded tank compressed-air circuit breaker of 10-million kva interrupting capacity.

New COMPRESSED AIR CIRCUIT BREAKER Design

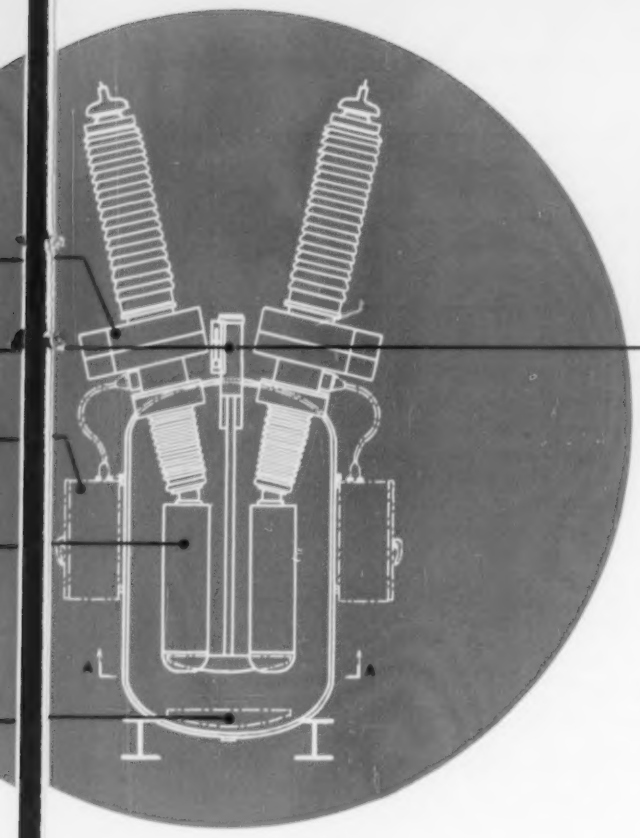
J. E. SCHRAMECK and R. E. KANE

Power Circuit Breaker Department
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

A new compressed-air circuit breaker for large metropolitan areas has been developed. This circuit breaker has many novel features. It combines the desirable features of oil circuit breakers and air circuit breakers. This attractive combination can be useful to utilities building substations where the presence of oil may be considered hazardous. The circuit breaker has been developed for 138 kv, 10 million kva initially, since this is the rating most often required for large metropolitan substations.

The use of compressed-air circuit breakers is not new. However, previous compressed-air designs have not had some of the most desirable features of oil circuit breakers. Some of these features, such as providing bushing-type current transformers and potential devices as an integral part of the breaker, have come to be considered almost essential by the American user. This new design, which retains the grounded metal-tank construction used in oil circuit breaker design but provides compressed-air interrupters, offers a logical solution. It also provides several other advantages of the oil-circuit breaker, such as mechanical position indication, mechanical auxiliary switch operation, and mechanical tie between poles.

The interruption of 10 million kva with compressed air seemed a logical extension in capacity since interrupters for 69 kv and 5 million kva have been developed. Two of these interrupters in series with proper control of the voltage distribution provide the necessary voltage level and current interruption.



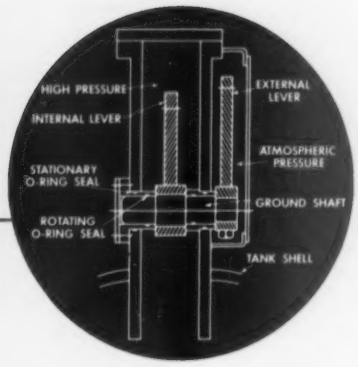
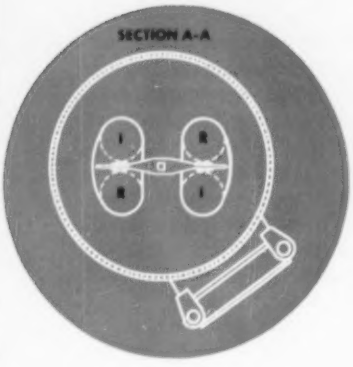


Fig. 2—Detail of pole-unit lever operating shaft and air seal.

Fig. 1—Cross section of a pole unit.



1. Bushing Current Transformers
2. Bushing Potential Devices
3. Contacts
4. Moving Contact Cross Bar
5. Pole Unit Levers
6. Resistor
7. Interrupter

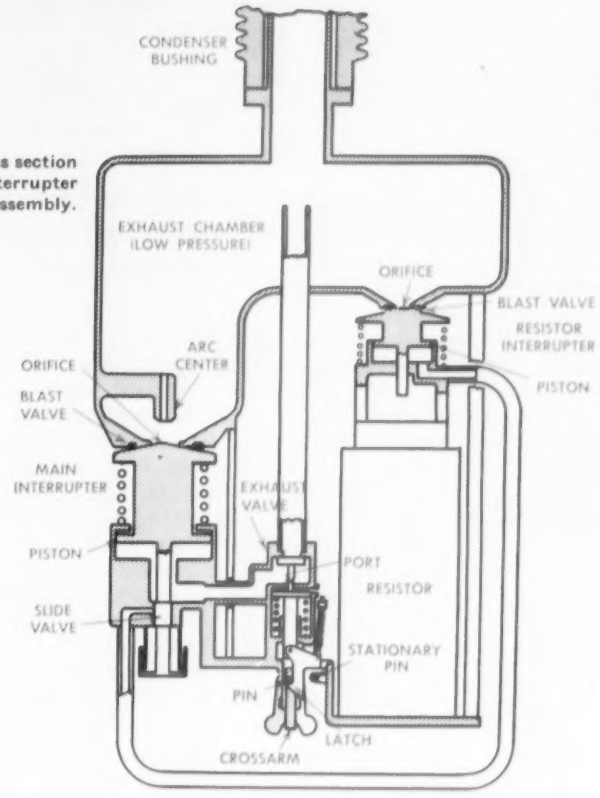


Fig. 3—Cross section of an interrupter assembly.

Compressed-Air Breaker Design

The circuit interrupters are suspended from the ends of the condenser bushings within a grounded tank (Fig. 1). Compressed air provides the necessary insulation between the interrupters and ground, and also serves as the interrupting medium. A conventional operating mechanism, driving all three pole units through a bell crank and pole unit levers, mechanically coupled by connecting rods across the tops of the air tanks, minimizes pneumatic variation in breaker operation. Air blast used in interrupting the arc is exhausted through the hollow bushings. Accurately machined shafts rotating in "O" rings provide mechanical connection between external levers moving in atmospheric pressure and the continuation of the lever system inside of the high-pressure tanks, so that air leakage between the two is eliminated (Fig. 2). By this means a conventional cross-arm isolator is moved downward, and provides isolation of the interrupters when the breaker is in the open-circuit position. The initial downward motion actuates the pneumatic operation of the interrupters.

The cross arm in the closed position connects two interrupter assemblies of a pole unit in series. These are two previously proven 69-kv interrupters, which when connected in series, provide for 138-kv operation. The cross arm is moved only by the external mechanism and remains either closed or opened. It will not reclose if air is drained from the tank.

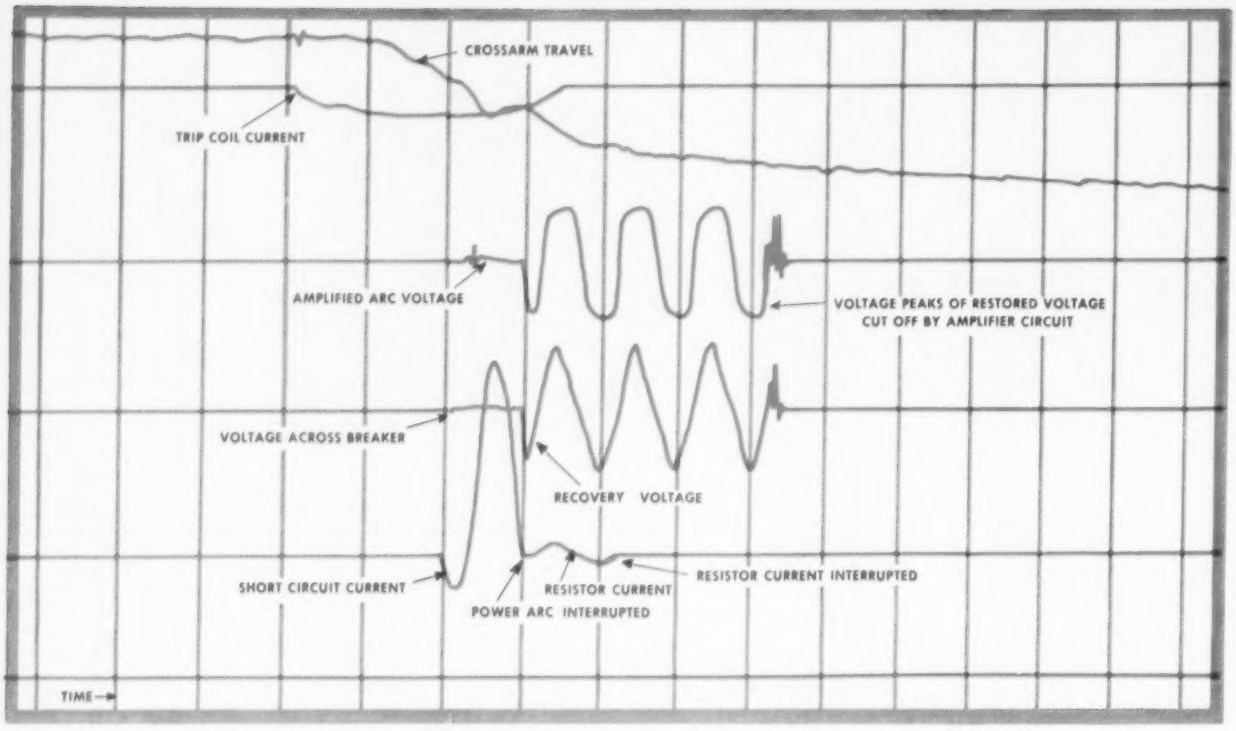


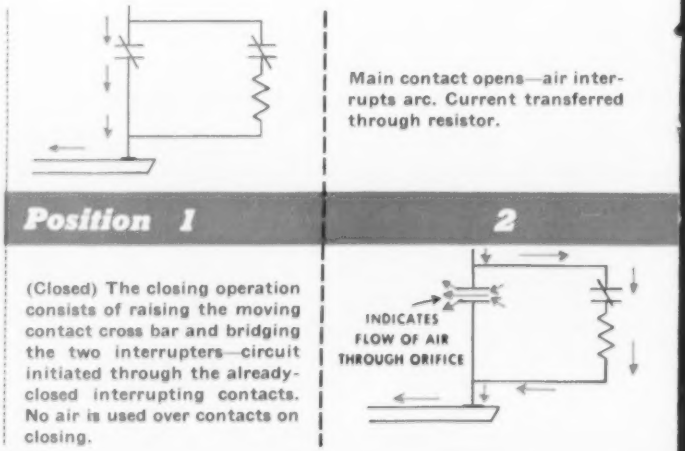
Fig. 4—Oscillogram showing interruption of 44 000 amperes on a single interrupter assembly at 35 kv.

Interrupter Operation

Upon opening the breaker, downward motion of the cross arm initiates pneumatic operation of the interrupters. Paralleling main contacts, which are built within the tanks, but external to the interrupters, are first opened. These main contacts form the guide members for the kick-out springs accelerating the cross arms downward. The action of the kick-out springs separates the main contacts first, and then the sequential pneumatic operation of the interrupters proceeds (Fig. 5).

Pins at each end of the cross arm (Fig. 3) operate a latch in each interrupter assembly. Attached to the upper end of the latch is an exhaust valve. The upper side of this valve is at atmospheric pressure, since the bushings to which the interrupter assemblies are attached are hollow, with the upper ends open to the outside for exhausting the air blast. As the exhaust valve is pulled from its seat by downward motion of the latch, a section within the interrupter assembly is exhausted to atmospheric pressure. This exhausts air from beneath the main interrupter piston, which is normally closed by biasing springs, and opens the main interrupter with an accompanying air blast through the orifice to the exhaust chamber and out through the hollow condenser bushing. The stem extending below the interrupter piston forms a slide valve, which on downward motion of the main interrupter piston, opens to exhaust air from underneath the resistor interrupter piston. Thus, this slide valve interlocks the main and resistor interrupters to insure that the main interrupter opens first. Consequently, the main contactor opens first, and the air blast interrupts the arc, transferring a portion of the current to the parallel resistor and resistor interrupter. The resistor contact then opens, and the air blast interrupts the resistor current. The resistor is of low ohmic value and functions to control the rate at which recovery voltage is applied to the interrupter when it opens.

This system eliminates the need for long connecting pilot air lines, which would make timing of the various interrupters a tedious and delicate adjustment. The pressure difference is obtained very near the point where forces are developed, and consequently, that portion of the overall breaker time required for pneumatic operation is held to a minimum. As a result, pneumatic variation between interrupters has a minimum effect on the overall timing between application of the trip impulse and the opening of any one of the interrupters. Adjustments of the pneumatic system to obtain


Main contact opens—air interrupts arc. Current transferred through resistor.
Position 1
2
(Closed) The closing operation consists of raising the moving contact cross bar and bridging the two interrupters—circuit initiated through the already-closed interrupting contacts. No air is used over contacts on closing.
INDICATES FLOW OF AIR THROUGH ORIFICE

simultaneous operation of the interrupters are not critical or difficult to obtain, and variations due to operation at different air pressures, for all practical purposes, have no effect on the overall breaker timing. Furthermore, variations in parting of the cross arms caused by friction of the lap-type contacts through which the cross arms move are of no significance, since the arc has been interrupted and the interrupting contacts remain open, pneumatically, while the cross arms are parting. The speed of cross-arm motion is deliberately slowed momentarily to obtain circuit interruption before cross-arm parting. The interrupter contacts are closed pneumatically after the cross arms have parted contact and isolated the interrupter assembly.

Reclosure of the interrupter contacts after the cross arm has moved a predetermined distance is initiated by disengagement of the latches from the cross arm pins. This allows the exhaust valve to reclose, which in turn introduces high-pressure air under the main interrupter and resistor interrupter pistons forcing them to their closed-circuit position.

Electrical Tests

Exhaustive tests made on the breaker were designed not only to prove the breaker electrically, but also to provide a maximum number of breaker operations for demonstrating its mechanical integrity. Altogether, some 4600 breaker operations made up the development tests on the breaker. Standard ASA tests were made at 250 and 200 psig, and all requirements as to impulse, potential, and temperature rise were obtained. Power tests demonstrated a 3-cycle interrupting time with closing and reclosing timing within 20 cycles on a 60 cps basis. Generally, impulse and potential tests show appreciable insulation strength down to 45 psig in the grounded tank. At atmospheric pressure, the breaker holds 120 kv to the grounded tanks. Thus in an emergency created by loss of air pressure, the interrupters will not flash over to the tanks at service voltage before the breaker can be isolated from the circuit.

Direct testing of the breaker to 10 million kva is not practical or economical. Since each pole unit is divided into two interrupter assemblies, testing by a unit method was done to double the effective power of the testing laboratory. Capacitors built into each interrupter assembly assure a 57–43 percent voltage distribution between the interrupters. Actually, for short-circuit interruption by the main contacts, the interrupter resistors provide a 50–50 percent voltage distribution; the capacitors determine voltage distribution only for interruption of the resistor currents.

To demonstrate the ability of the breaker to handle magnetizing currents of transformers, six power transformers were switched singly and in multiples, one against the other, at 88 kv. All tests were successful. Since the breaker may be used on cable circuits or for capacitor switching, repeated single-interrupter tests were made at currents up to 500 amperes at 70 kv.

Single-interrupter tests were made interrupting currents in excess of the rated 44 000-amperes capacity of the breaker. Upon completion of single-interrupter tests, both interrupters were connected together and operated as a single-pole unit up to the maximum capacity of the laboratory at rated voltage. Throughout these tests the arcing time was uniform for all values of current. That is, the breaker generally interrupted at the first current zero occurring after contact separation. When this contact separation was insufficient to obtain interruption, the breaker always cleared on the second current zero; thus, arcing time varied from about 0.2 to 0.7 cycles. This very low arcing time resulted in negligible energy dissipation at the contacts and long contact life.

Conclusions

The adequacy of compressed air as an insulating and interrupting medium to meet all voltage requirements of a 138-kv circuit breaker has been fully demonstrated. In addition to its interrupting ability some of the other features of this breaker are: (1) A dead (grounded) tank construction similar to that used on conventional oil circuit breakers. This feature makes the breaker inherently safe, sturdy, and compact. (2) The three-pole breaker is built as a unit on a single base and can be delivered fully assembled. (3) Porcelain is used only on the entrance bushings and this is applied with all forces in compression. The porcelains do not form the storage and enclosure for high-pressure air. (4) Simple and relatively inexpensive current transformers are mounted on the bushings just the same as for oil breakers. All standard accuracies for relaying and metering can be obtained. (5) The bushings are equipped with potential taps so that potential devices can be mounted directly on the breaker tanks. This eliminates the requirement of externally mounted potential transformers. ■

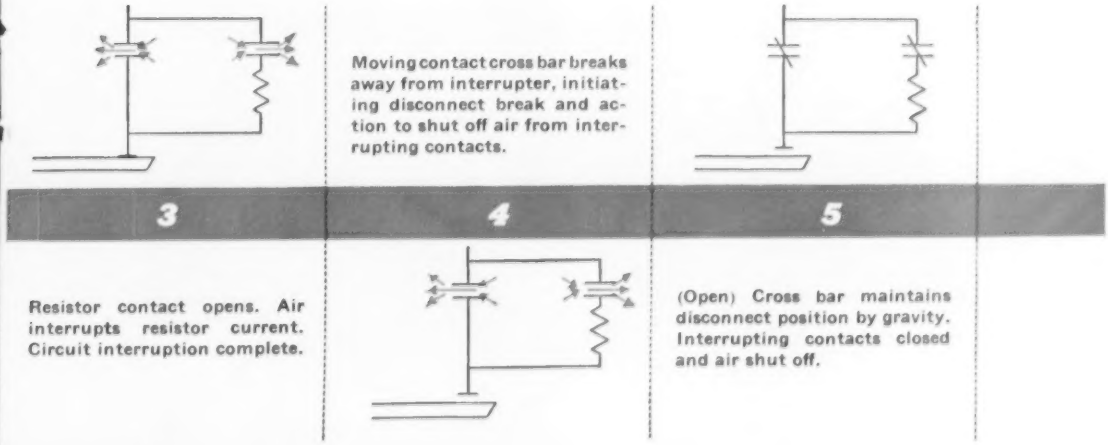

Moving contact cross bar breaks away from interrupter, initiating disconnect break and action to shut off air from interrupting contacts.
3
4
5
Resistor contact opens. Air interrupts resistor current. Circuit interruption complete.
(Open) Cross bar maintains disconnect position by gravity. Interrupting contacts closed and air shut off.

Fig. 5 — Sequential operation of the interrupter assembly.

A-C CRANE CONTROL

Fig. 1—Load-O-Matic helps install the reactor vessel in the atomic power plant at Shippingport, Pa.

H. A. ZOLLINGER

Material Handling Section
Industry Engineering Dept.
Westinghouse Electric Corp.
East Pittsburgh,
Pennsylvania

WITH LOAD-O-MATIC

▪ The Load-O-Matic crane-hoist controller was developed several years ago to provide a-c operated cranes with a smoothness of operation comparable to that obtained with d-c adjustable voltage and performance better than constant-potential d-c. A recent improvement in the Load-O-Matic system eliminates all reversing contactors so that only a main-line contactor, two saturable reactors, and a transformer are needed for motor reversing. The transformer and reactors are static devices and will outlast many sets of contactors. The one main-line contactor is closed when the drive is started and opens approximately three seconds after the drive stops. While the main-line contactor is closed, reactors are used to reverse the motors. Many operating cycles can be completed before the main-line contactor reopens. Consequently, a single contactor has replaced two mechanically interlocked contactors and on most applications operates about one-fourth, or less, as often as conventional reversing contactors.

The Load-O-Matic controller has only two accelerating contactors (in the motor secondary) as compared to four or five for a standard a-c crane controller. Along with fewer con-

tactors there are only two accelerating relays instead of three or four for other a-c crane-hoist controllers. By keeping contactor operation to a minimum, the control maintenance is greatly reduced.

Saturable Reactor Operation

Both speed and direction of the driving motor are controlled by changing the excitation between two saturable reactors. The method of accomplishing this is shown in Fig. 3. Forward rotation results when the forward reactor is saturated by its control winding, and the reverse reactor unsaturated, so that a positive-sequence voltage is applied to the motor. A negative-sequence voltage is applied by unsaturating the forward reactor, and saturating the reverse reactor. Sub-synchronous operating speeds are obtained by using combinations of forward or reverse reactor impedance. This provides an adjustable, unbalanced voltage to the motor, and causes the rotating magnetic field of the motor to become, in effect, elliptical, which results in a net decrease in torque. This is illustrated in Fig. 3d where the area within the ellipses indicates the magnitude of the torque developed at various degrees of unbalance.

Accelerations and decelerations are inherently smooth with this single-phase reactor system. Since both reactors are in series with one motor terminal, they are at some degree of unsaturation and oppose current changes or torque changes. From test data, the time for torque changes is from 0.2 to 0.4 second. Modern d-c adjustable-voltage crane controllers require about 0.3 second for a change from zero to full-motor torque or vice versa, and are accepted as the ultimate in smoothness. This is in contrast to normal a-c wound-rotor motor controllers that permit peak motor torques of approximately twice full load with 0.008 second when the load changes from zero to full load.

Speed is stabilized for given load and reactor setting with a d-c tachometer (Fig. 4a). As speed changes, the tachometer supplies a corrective voltage to the reactor control winding and alters reactor saturation accordingly. Relative changes in strength of the forward and reverse reactor control fields for a new speed setting are made by altering the bias voltage. To obtain greater torque in the forward or reverse direction, the motor external secondary resistance is changed with contactors.

Speed-Load Curves

To provide the crane-hoist speed-load curves shown in Fig. 6a, the controller uses a four-point master switch and two accelerating contactors and relays. The first and second hoist points use full secondary resistance; the third and fourth hoist points are obtained by closing secondary contactors 1A and 2A respectively (Fig. 4a).

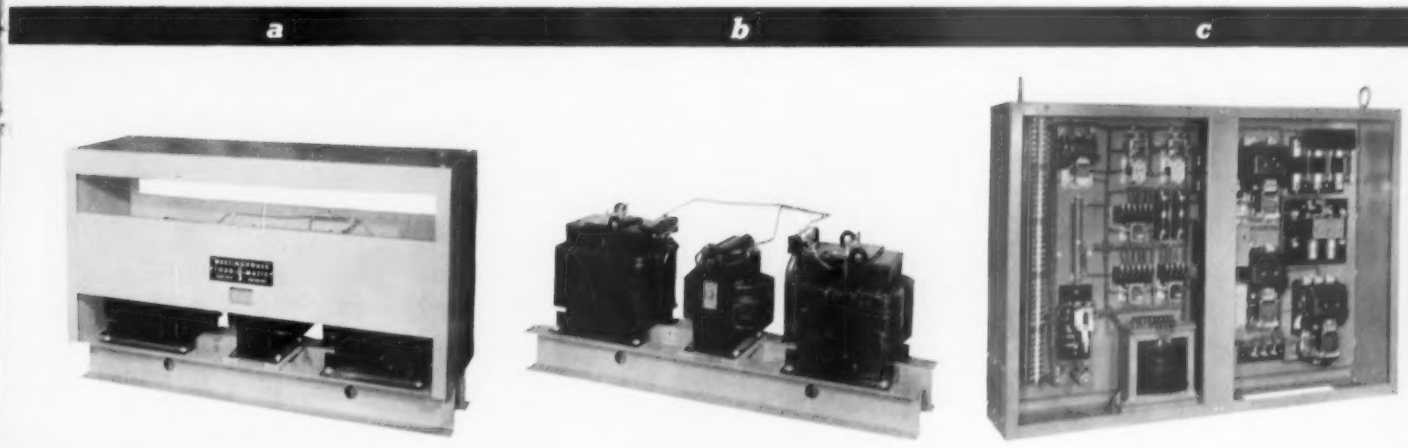
In the lower direction, points one, two, and three are all with full-secondary resistance, and without any secondary contactor operation. The fourth point lower provides regenerative lowering by closing secondary contactor 2A and fully saturating the down-torque reactor.

The first hoist point shows the highly desirable slow, light-load speeds. This curve is adjustable during installation from 30 to 90 percent speed at no load, but from experience the curve shown is the most used. The other hoist-point curves are basically the same shape as standard a-c speed-load curves. The first three lowering points are obtained immediately when the master switch is placed on the desired lowering point. This is patterned after the constant-potential d-c and adjustable-voltage d-c performance, but is not found on all a-c controllers. The constant-potential d-c lowering curves and the Load-O-Matic (one through three) lowering curves are identical in first-point speeds at all loads and in the general slope of other curves. While these lowering curves can be adjusted, experience has indicated the recommended curves shown are generally used.

Adjustable Speed Range With Vernier

Over 90 percent of crane operations do not require close spotting of the loads and thus do not generally require much inching of the control. The other five or ten percent of the operations require inching, and represent the majority of the contactor and brake operations. These contactor and brake operations can be eliminated with a vernier control. This is a vernier (rotary transformer) that feeds a signal into the main reactors. When the load is close to the desired location, the main master switch is left in any of the first three lower points and the foot or hand operated vernier control is used to hold the load in position. If the crane must hold the load for over 10 to 20 seconds, the operator first puts the load in the correct spot with the vernier and then centers the main mas-

Fig. 2—(a) Exterior view of ventilated reactor and phase-shift transformer assembly. (b) Reactor assembly without enclosure showing (left to right) down-torque reactor, phase-shift transformer, and up-torque reactor. (c) Interior view of control panel showing the front wiring, the front connection, and the steel panel.



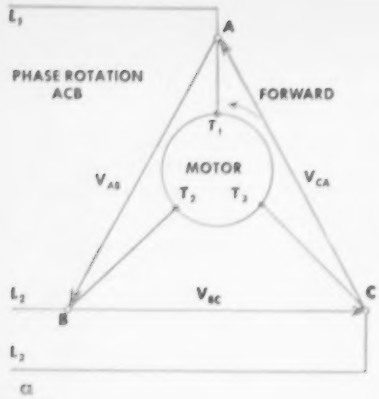


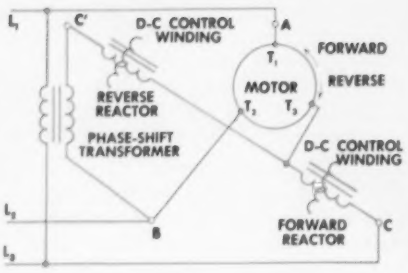
Fig. 3—Latest improvement in Load-O-Matic crane control provides reversing direction of a-c motor without reversing contacts.

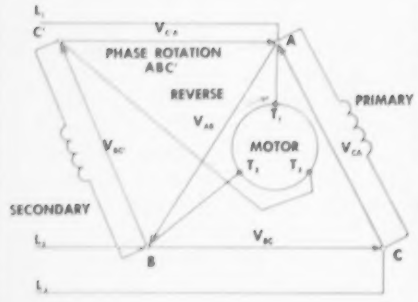
a Forward motor rotation is provided from phase rotation ACB. If motor terminals T1 and T2 remain connected to phase A and B respectively, but T3 is connected to C′, which is 180 degrees out of phase with phase C, phase rotation is reversed.

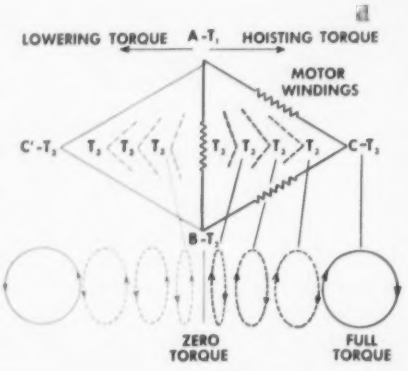
b Phase C′ is established by connecting the primary of a 1-to-1 turns-ratio transformer across lines L1 and L3. By connecting one terminal of the secondary to phase B, and properly phasing this transformer, C′ is established.

c If saturable reactors *forward* and *reverse* are inserted as shown, forward or reverse rotation can be provided. The reactor is the equivalent of a closed contactor when it is fully saturated, and an open contactor when unsaturated. Besides providing full-forward or full-reverse rotation when one reactor is fully saturated and the other unsaturated, intermediate values of forward—or reverse—reactor impedance provide sub-synchronous operating speeds.

d The shape of the magnetic field of the motor for various degrees of voltage unbalance can be represented by ellipses. The area within each ellipse is proportional to the magnitude of torque developed for each degree of unbalance.







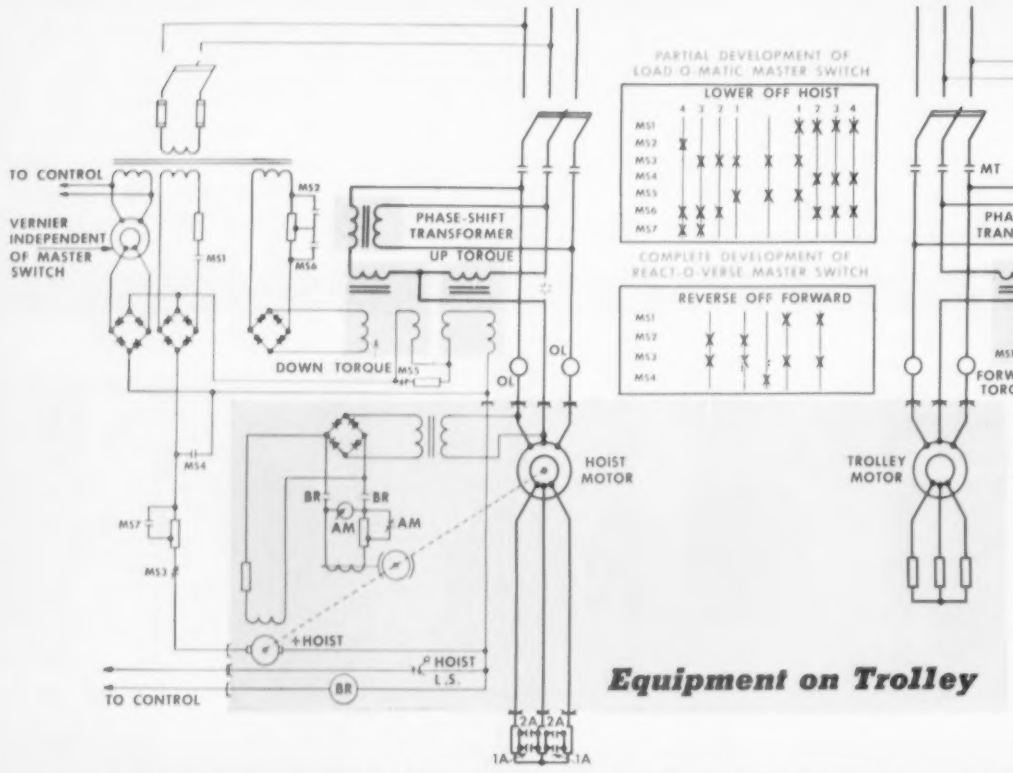


Fig. 4a—Load-O-Matic hoist basic schematic diagram.

Fig. 4b—React-O-Verse trolley complete schematic diagram.

ter switch. This sets the brake without changing the load position. The vernier provides the infinite speed control shown in the shaded area in Fig. 6a.

Motor Braking

Previous a-c crane controls rely completely on the magnetic brake to stop the load when the master switch is centered. The Load-O-Matic crane-hoist system forces the motor to provide braking torque along with the magnetic brake and provides a faster and more positive stop. This motor braking can be provided because the main-line contactor is kept closed for three seconds after the master switch is centered. For safety, the brake leads are connected ahead of the motor but on the motor side of the main-line contactor, the reactors, the crane collectors (if used), and the power-limit switch (if used). The brake will set independent of master-switch position if power should fail, the main-line contactor coils burn out, collector shoes come off or break, the overload relays trip, motor leads burn out, the master relay coils burn out, or the overhoist limit switch trips.

Flexibility

When Load-O-Matic drives are 150 hp and larger, amplification is necessary between the power reactors and the pilot devices. This is because the reactors must be larger and require greater d-c ampere turns for saturation, and it is desirable to keep the pilot devices as small as before. For this reason, magnetic amplifiers are added as a speed regulator. The speed-load curves for drives 100 hp and larger are nearly flat, and approach heavy-duty adjustable-voltage performance. The speed droop can be adjusted to 3 percent or greater.

The Load-O-Matic system is not limited to main and auxiliary hoist drives on a crane. The principle has been applied to the trolley and bridge motions of overhead cranes. This type of control is called React-O-Verse (Fig. 4b); speed-torque curves for a trolley drive are shown in Fig. 6b. Elimination of all secondary contactors and relays reduces the power collectors from 6 to 3, and further reduces electrical and mechanical maintenance. The drive provides infinite speed range at all loads between zero and full speed and a variable value of plugging torque, depending on the master switch position, to afford better control of hook or bucket swing.

For a bridge drive, with higher inertia than a trolley, one or two secondary contactors may be added to obtain higher acceleration rates up to full speed.

Load-O-Matic has also been built for raising and lowering movable railroad and highway bridges, and for high-precision manipulators in atomic-power plants where spotting can be done with accuracy better than 20 thousandths of an inch. It is also being considered for mine hoists, machine tools, and many other applications. Another recent advance was the installation of Load-O-Matic drives in a large steel mill on two 60/15-ton gantry cranes for slag-pot handling, scull-cracker work, magnet work, and clam-shell bucket work.

The Load-O-Matic crane-hoist control has made possible the use of a-c power cranes in many applications where continuous handling or close control is required. Also it is especially suited where d-c or a-c power will have to be brought in because of the more economical transmission of a-c power. The lack of good slow-speed performance and high maintenance are the principal drawbacks of most a-c systems. Load-O-Matic has overcome these problems. ■

REFERENCES

"Load-O-Matic A-C Crane-Hoist Control," by W. R. Wickerham, *Westinghouse* ENGINEER, March 1952, p56.

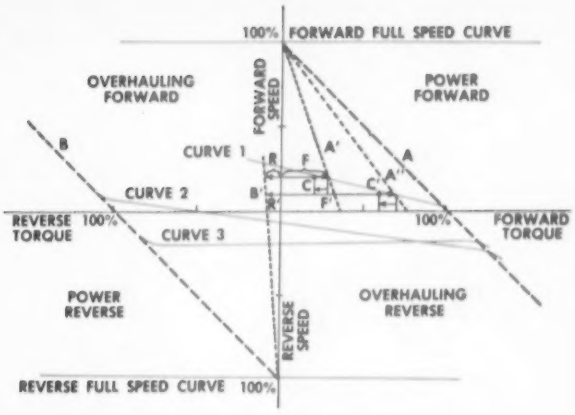


Fig. 5—The curve shows graphically how sub-synchronous operating speeds are obtained. Curve 1 represents a new speed-torque curve which will be established going through points C and C′. The dashed lines A and B are forward and reverse motor speed-torque curves with 100-percent external resistance in the motor secondary corresponding to 100-percent full-load torque at breakaway. By selecting the proper value of d-c control field current on the forward reactor, curve A′ is obtained, and in a like manner, the reverse reactor can simultaneously provide a value of reactance to give curve B′.

For 20-percent forward speed, torques proportional to F and R are developed by the positive and negative sequence voltages. The algebraic sum of these torques produces point C. If saturation of the forward reactor is changed to obtain curve A′, and speed is at 10-percent, the point C′ is established. This change can be accomplished manually, but is easily done automatically with an a-c or d-c tachometer, connected to the motor shaft, and its output voltage applied to the reactors. With this signal, an infinite number of speed-torque points can be established, to obtain a speed load curve for a given saturable reactor bias-voltage setting. To obtain other curves, the relative strength of the forward and reverse reactor control fields are changed by changing the bias voltage.

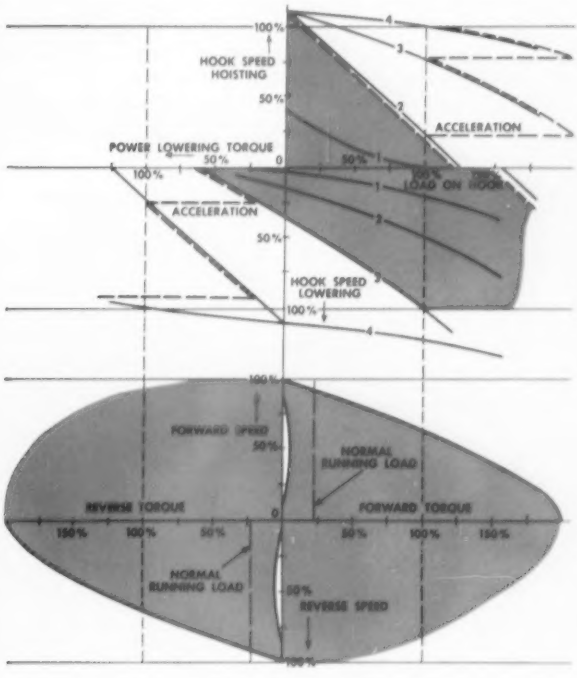


Fig. 6—(a) Speed-load curves for standard a-c wound-rotor motor with Load-O-Matic controller. Vernier control can provide infinite speed control in the shaded area. (b) Speed-load curves for React-O-Verse with infinite speed range.

FLASH EVAPORATOR FOR DISTILLATION OF SEA WATER

A practical large-scale method of producing fresh water from salt water has many potentialities. One approach is through flash evaporators.

R. L. COIT

Supervisor, Development and Application Section
Heat Transfer Apparatus Dept.
Westinghouse Electric Corporation
Philadelphia, Pennsylvania

Y. S. TOULOUKIAN

Associate Professor
Mechanical Engineering
Purdue University
Lafayette, Indiana

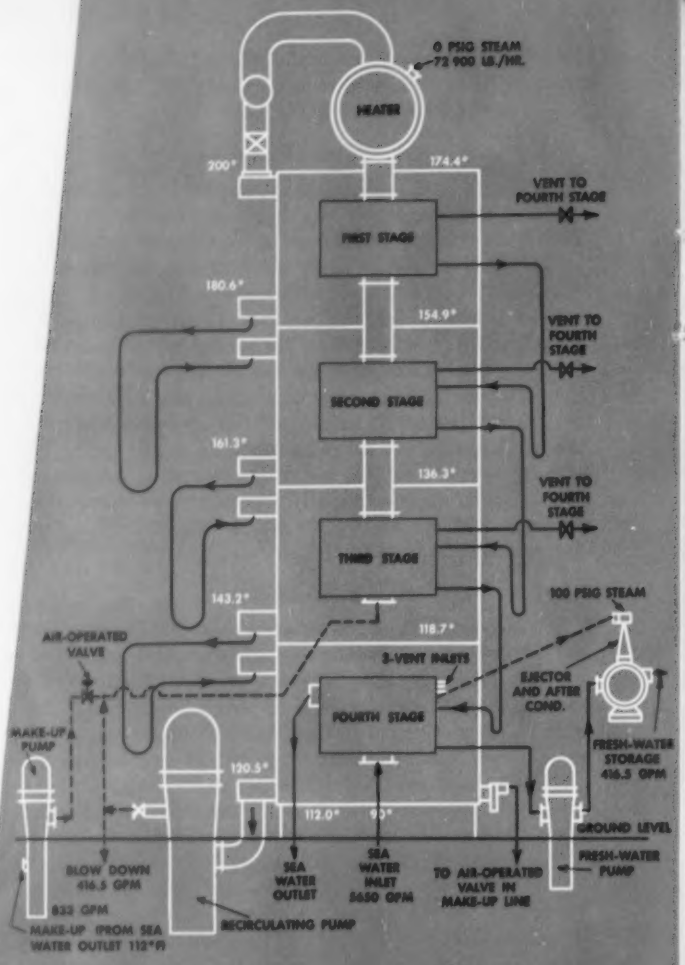


Fig. 1—Above proposed arrangement of a Westinghouse multi-stage flash-type evaporator.

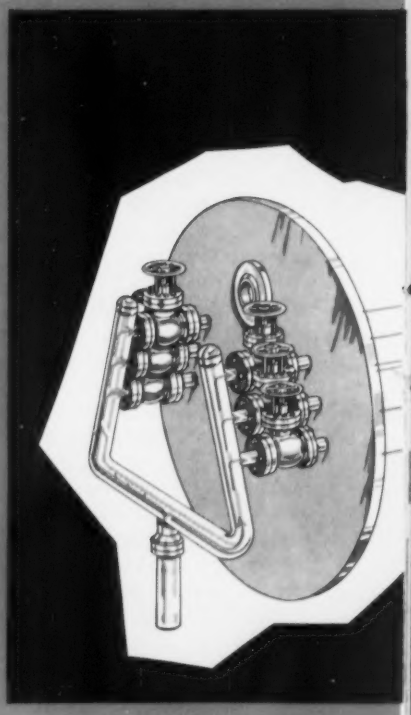


Fig. 2—Cutaway sketch of the Westinghouse experimental flash evaporator showing the flow paths and function of the various components.

▪ Acute shortages of fresh water exist in many areas of the world and the economic development of these regions depends to a large extent upon an economical method of producing potable water and water suitable for power production and process uses. This has led to increasing interest in the conversion of sea water and other saline or polluted water into a potable form. Flash evaporation offers many advantages for this purpose.

Most sea water contains approximately 35 000 parts per million (ppm) of total dissolved chemicals. Although in some locations water containing 4000 ppm total dissolved solids is used daily for drinking, more acceptable limits of purity range from 500 to 1000 ppm. Thus the dissolved solids in sea water must be reduced by a factor of 70 to render it acceptable for drinking purposes.

Distillation of sea water as a means of obtaining potable water is not new. However, recently major advances have been made in the art of sea-water distillation. Potable water in large quantities is produced in the modern units of triple-effect submerged-tube evaporators in operation in Kuwait, on the Persian Gulf. Small stills operated on solar energy were developed during the last war for use on life rafts and in remote locations. Experimental research and development is in progress in this country and abroad for larger installations of this type. Attempts have been made to produce potable water through flash evaporation of the relatively warm surface waters of the seas, heated by the sun; the much colder waters from greater depths were used to condense the distilled vapor after it had expanded through a turbine generating sufficient electrical power to drive the necessary pumping equipment. Recent studies of such self-operating installations seem to indicate the near practicability of such a cycle, since favorable oceanographic thermal gradients are found to exist in the deep coastal areas of some parts of the world. In all these efforts, the main goal is the production of fresh water from sea water at low, or zero operating cost.

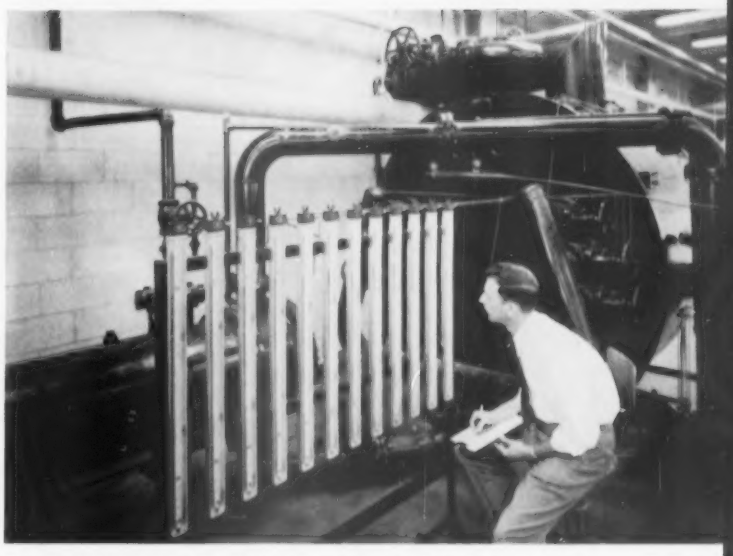
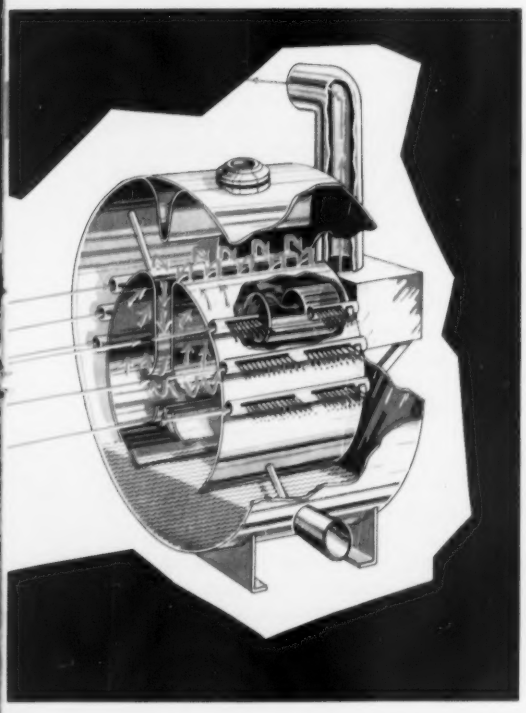


Fig. 3—Laboratory view of the Westinghouse experimental flash evaporator undergoing performance characteristics tests. The heat exchanger shown at the left supplies the hot salt water.

The process of flash evaporation is ideally suited for the distillation of sea water irrespective of the source of energy used. Even though the principle is not new, its large-scale application to the production of fresh water from sea water is comparatively recent.

Flash evaporators of the type discussed here have several advantages. Low-temperature waste-heat sources can be utilized. Sustained high efficiency of operation can be obtained since evaporation takes place on the water droplets rather than on tubular heat-transfer surfaces, which corrode and scale. Multiple-effect arrangements can be used with low temperature differences. The equipment is greatly reduced in weight and space requirements compared to conventional shell-and-tube evaporators. Initial cost is lower and maintenance time and expense are reduced to a bare minimum.



Mechanism of Flash Evaporation

The maximum amount of vapor evaporated in flashing saturated water from a high pressure to a lower pressure is given by the thermodynamic equilibrium states of the water before and after flashing. This information can be obtained from steam tables or charts (or tables of thermodynamic properties of salt-water solutions). The information in these tables is based on complete thermodynamic equilibrium conditions existing between the vapor and liquid phases in mutual contact. Since in actual processes such equilibrium conditions are not present, two methods are used to approach equilibrium—promoting turbulence, and increasing the effective surface area for maximum evaporation. In this connection, a common belief is that fine atomization of a stream of water is most effective in presenting a large surface for evaporation. Sometimes overlooked is the fact that increasingly finer atomization approaches a diminishing rate of returns rapidly with an accompanying adverse effect on carry-over.

The mechanism of flashing saturated or metastable water is similar to an "explosion" of a sheet of water. This is primarily due to the rapid increase in the volume of dissolved

gases and preformed nuclei within the bulk of the water, caused by the decrease in pressure at the instant of flashing. The major portion of the vapor release takes place almost simultaneously with the disintegration of the liquid mass. Therefore, beyond a reasonable degree of breakup any further atomization rapidly reaches a state of diminishing returns, because of the small temperature differential present between the fine liquid particles and the vapor surrounding them. In other words, droplet formation and vapor release essentially take place simultaneously and fine droplets are relatively low in average temperature at the very outset, thus contributing only a small fraction of the total vapor released by surface evaporation.

General Design Considerations

Certain criteria must be established in the design of flash-evaporation equipment for sea-water distillation. The temperature of the feed should be as low as possible to enable the utilization of low-grade energy sources available, and to minimize serious corrosion problems encountered at high temperatures. The temperature difference available for flashing should be as high as possible, from the vapor release standpoint, because the percent of flashed vapor is proportional to the temperature drop (being almost 1 percent for each 10 degree F drop in temperature within the range of 100 F to 200 F). High fractions of vapor released per pound of water circulated result in smaller pumping power requirements for a given vapor generation capacity.

Within these features conflicting interests are evident. The lower the temperature of the feed and also the greater the temperature drop in the flashing process, the greater the specific volume of the vapor becomes (nearly inversely proportional to the pressure level in the evaporator). This necessitates large piping and large evaporator volumes to keep the vapor velocities within a reasonable range and thus avoid large friction losses and excessive carry-over.

The Experimental Evaporator

An experimental flash evaporator has been constructed to obtain performance data necessary for the future design of full-size commercial units. The unit is shown under test in the Westinghouse development laboratory in Fig. 3; a cutaway sketch showing the functions of the various portions of the test evaporator appears in Fig. 2. The cylindrical shell is 84 inches inside diameter by 3 feet long. To build a higher capacity unit, the same diameter could be maintained and the shell length increased to any required value.

Heated sea water enters the six 3-inch spray pipes and is discharged through slots into the shell (Fig. 2). Since the shell is maintained at a reduced pressure, a portion of the water flashes into vapor. The major portion of the remaining liquid falls into the sump in the bottom of the evaporator, but the smaller droplets are entrained by the vapor, which flows upward and into the vertical central passage constituting a two-dimensional accelerating nozzle. In this nozzle the wet vapor is accelerated and subsequently reversed in direction. Because of their greater momentum the denser water droplets impinge on the water surface below, while the relatively dry vapor is reversed in direction and led away. Thus, all but the smallest of the entrained droplets are separated. The vapor is then condensed in an external condenser.

In the test facilities employed for the performance testing of the experimental flash evaporator, synthetic sea water is circulated through a heat exchanger, where heat is added to increase the water temperature to the desired value. The water then flows through the slots in the spray pipes and into a lower pressure region in the shell. A portion of the water is vaporized and the remaining liquid is recirculated.

A liquid-level control in the evaporator actuates a make-up water system and admits water to maintain a constant water level in the evaporator shell. A vapor sampling system extracts a sample of wet vapor, condenses the vapor and measures the purity of the condensate. The solids content of the circulating sea water is measured by an immersion-type conductivity cell. A separate conductivity cell measures the purity of the condensate as it leaves the hot well of the condenser. This condensate includes the steam that is condensed in the heat exchanger, hence the solids content in the heater drain also must be measured.

Test Results

One problem studied was the determination of the effectiveness of flashing of sea water. A comparison between the measured evaporator sump temperatures and the saturation temperatures for pure water showed the difference between the two temperatures to be nearly 1.5 degrees F. For a shell concentration of 37 000 ppm the true equilibrium temperature is very nearly one degree F higher than that for pure water in this range of temperatures. Hence, the unflashed portion of the water comes within 0.5 degrees F of the equilibrium temperature, thus giving flashing efficiencies of 90 percent and 97 percent, corresponding to temperature drops due to flashing of 5 and 30 degrees F, respectively. This particular design therefore is capable of providing adequate atomization and vapor release time for almost complete equilibrium to be reached.

The over-all test results for the test evaporator show that for a shell pressure of 4 inches of mercury the experimental evaporator will produce 16.6 gpm water at a solids content of 150 ppm when the feed inlet temperature is 154 degrees F.

Summary of Progress

Several conclusions can be drawn from these studies. The flash evaporator of the type discussed here provides an economical means of producing potable water from sea water or polluted water sources when a low cost source of heat is available. Various waste-heat sources can be utilized to heat the low-temperature feed water. Among many possibilities of heat sources are the exhaust of open-cycle gas turbines, the exhaust of standard steam turbines, low-pressure steam from waste-heat boilers, and the moderately hot water from final coolers on refinery heat exchangers, in which case the water heater can be eliminated. Water heated by solar energy could also be used.

The design of this experimental evaporator is ideally suited for the incorporation of an internal condenser with a removable shell. Such an arrangement will further simplify the plant operation, eliminate piping losses, and save space.

The unit is readily adaptable for multi-staging in a compact stack arrangement, thus further increasing its vapor output per unit heat input. One proposed arrangement is shown in Fig. 1. This multi-stage unit would produce 2.86 pounds of fresh water per pound of saturated steam at atmospheric pressure.

Because of its extremely simple design features, such integral condenser-evaporator package units can be manufactured at low cost. Furthermore, since such a system can be installed outdoors, its installation costs will be low. Operational and maintenance costs are at a minimum and no complicated controls are necessary. ■

WHAT'S NEW!

Symbolizing its ability to probe the atomic structure of matter, the world's most powerful crystallographic x-ray machine is seen through an intricate pattern depicting an atomic structure.

'Most Powerful' X-Ray Machine Traces Atomic Changes in Metals

▪ Hitherto unknown changes in the atomic arrangement of iron-aluminum alloys have been discovered through the use of the world's most powerful crystallographic x-ray machine at the Westinghouse Research Laboratories. Valuable for their superior magnetic properties, iron-aluminum alloys may find wide application throughout the electrical industry for such apparatus as generators, transformers, circuit breakers, and similar electrical equipment.

For example, new information on the previously puzzling behavior of iron-aluminum would give metallurgists greater insight into these metals. Previously, scientists were able to observe that at certain temperatures, iron-aluminum reacted in unexpected ways. They were aware of these changes but were unable to understand or explain them. With the new high-intensity x-ray machine, x-ray photographs of these alloys can be taken during the precise moments when, due to temperature changes, the magnetic arrangement of atoms in the metal is undergoing transformation.

This is because the crystallographic x-ray machine is at least 15 times more powerful than any comparable device now in existence, so that x-ray time has been reduced sharply on iron-aluminum and other alloys under investigation. This unusually high power—and the fact that the x-ray beam can be concentrated on a focal spot less than half the normal size—provides an x-ray source that is 15 times more brilliant. Thus, x-ray photographs can be taken in one-fifteenth of the usual time, collapsing hours of normal work into a relatively few minutes.

Because of its unusually brilliant x-ray source, the super-powered machine makes possible metals research that previously was considered too costly or otherwise impracticable. Especially is this true in cases where metals must be tested at high or low temperatures. X-ray photos have been taken at temperatures as low as 300 degrees below zero Fahrenheit. This conceivably could be accomplished with less powerful equipment, but it would be difficult to maintain accurate temperature control, and because of the long exposure time which would be necessary, the cost of liquid helium—the cooling agent—would be prohibitive. By reducing exposure time to one-fifteenth of that formerly required, the cost of liquid helium needed for cooling is reduced proportionately.

In addition to conducting studies at low temperatures, metals have been photographed in a super-heated state. X-ray "snap shots" of metals as hot as 3000 degrees F have been taken, making possible the study of characteristics of the metal before it vaporizes or undergoes some chemical change at the elevated temperature.

The machine is also equipped with an adapter that gives an x-ray beam only 400 millionths of an inch in diameter—about one-tenth the diameter of a human hair. This thin, intense beam approaches the dimensions of the tiny crystallites which make up the crystal of a metal, and permits the investigation of individual crystals with an exactness not possible with a beam of larger size. ▪

Designers of airborne radar gear recently needed a new tube. The tubes available were either physically too large, or did not have a reasonable factor of safety in electrical rating. Tube designers came up with the WX-3574, a ruggedized tube of small size. Furthermore, in a radar system, the tube is capable of three different functions; it can serve as a clipper diode, a charging diode, or a power supply rectifier. As a clipper, it prevents false signals (undesired pulses from the magnetron due to unavoidable circuit operations); as a charging diode, it supplies current to the magnetron circuit; its power-supply rectifier duty is conventional current rectification.

To keep the weight to a minimum, an aluminum radiator is used, which is attached to the copper anode using ultrasonic soldering techniques. The external anode is forced-air cooled.

This is the rotor of a tiny torque-motor designed for use in a miniature gyroscope. Preformed flat coil is fastened to the surface of the cylinder so that conductors are parallel to and at constant radius from the rotor axis. Surrounding this is the stator, a permanent magnet in a flux return ring.

Meter Motor for Miniature Gyroscope

▪ The d'Arsonval movement, well known in meter and instrument circles, has been adapted for use in a miniature gyroscope. The d'Arsonval movement incorporates a moving coil with a stationary core, which results in a very linear torque-current input relationship, with no residual torque for zero input such as is present when a moving magnetic element is employed.

The d'Arsonval torque-motor was developed for use in a miniature gyroscope especially designed for fire-control systems. The torque-motor is one of four fundamental components that make up the gyroscope assembly; the other components are the gyroscope spin-motor, the position detector, and the damper.

This gyroscope is a single-degree-of-freedom instrument employing a fully-floated gimbal; and by virtue of the damping provided by the viscous flotation oil may be employed not only as a "rate" gyro, but as an "integrating" gyro.

When the gyro is subjected to a rotation, the spin-motor produces a torque proportional to the rate of rotation, causing the gimbal to rotate relative to the gyro case. This motion is detected by the position detector and by means of a feedback amplifier a current is delivered to the torque-motor. The torque-motor generates the restraint necessary to balance the precession torque produced by rotation of the gyro. The current fed to the torque-motor is proportional to angular rate; consequently, this current is a measure of the angular rate of change of angular position in space, and is the output of the rate gyro.

When employed as an integrating gyro, the damper provides the gimbal restraint, and the torque-motor is then used to command the gyro. The output in this case is obtained from the position detector and is the time integral of the rate of change of angular position.

Of particular interest is the concentric construction of the torque-motor, developed for ease of assembly. The rotor is a low-inertia, non-magnetic coil form, on which a preformed, flat coil is fastened so that all conductors lie on the surface of a cylinder and so that the working conductors lie parallel to and at a constant radius from the rotor axis. Surrounding this movable coil is a stationary structure. The stator consists of a permanent magnet mounted within a flux return ring which surrounds the rotor. The magnet provides a constant flux field in which the rotor winding operates. The torque-motor thereby combines the highly desirable linear torque-to-input current characteristic typical of the d'Arsonval movement, but at the same time provides a torque-motor with high necessary torque; the gyro torque-motor develops torques greater than 3000 dyne centimeters without any signs of saturation or hysteresis. ▪

Cooling Aircraft Electronic Equipment

▪ Cooling of electronic equipment aboard high-speed aircraft is a major problem. Two choices are available to designers of electronic equipment; either build the cooling system for the equipment, or build the equipment so that it can withstand high ambient temperature operations. The unit being placed in an oven for tests (below) is designed for operation at 400 degrees F. This requires use of special high-temperature components, along with special construction techniques with heat-transfer paths optimized for maximum heat conduction. For example, ordinary solder will melt at this temperature. Consequently, a special high-temperature solder

A radar coupler being placed in an oven for temperature tests.

is used, and is melted with a device that almost amounts to a junior-sized spot welder.

The device shown is a radar coupler, a unit that couples a fire-control system to the automatic pilot control system, to automatically zero an airplane in on its target. This is a redesign of a standard coupler, and the performance of this unit will be compared with the standard used with a cooling system, both size wise and performance wise. Biggest advantage of the high-temperature equipment is that some of the space that would be required by a cooling system can be conserved, and the added complexity of a cooling system is avoided. ■

Etch Pits and Domain Patterns

■ In "grain-oriented" metal sheets, individual crystallites or grains are lined up such that magnetic flux has an easy path of travel along a given sheet direction. Development of these "grain-oriented" materials requires knowledge of the types and distributions of grain orientations at different stages of processing. A technique recently developed by materials engineers makes use of both etch pits and domain patterns to supply this type of information.

Etch pits are produced by special etchants that attack a polished sheet locally to reveal planes parallel to the faces of the unit cube of atoms that make up the grains. The angles these faces make with the surface in a given grain, then, determine the alignment or orientation of that particular grain.

Domain patterns, in turn, are obtained by applying a thin layer of colloidal suspension of magnetite particles to a polished surface. Each individual grain is made up of domains, or regions that are magnetized differently from each other. Where domains meet, free magnetic poles are created at the surface and collect the magnetite particles, thus outlining the domains. The exact pattern produced again depends on the angle of intersection of the surface with the unit structural cell, and thus the domain patterns also serve to reveal the grain orientations.

The etch pit and domain pattern techniques, used together, enable an observer to quickly determine: how much of a given grain orientation is present; how neighboring grains are oriented with respect to each other; how different orientations are partitioned between grains of different sizes; and how much individual grains deviate from a given orientation. These techniques thus provide an important tool in the development of better magnetic materials. ■

Whiskers Aid Study of Atomic Forces

■ One of modern science's oddities—highly pure and perfect metal crystals known as "whiskers"—are enabling scientists to gain new insight into the enormous forces that bind atoms together. A new technique enables evaluation of these forces by measuring the tensile strength of whiskers of iron and silicon.

This technique is one of the most accurate methods known for pulling apart the tiny crystals and measuring directly the applied force (stress) and the amount of stretch (strain) they undergo. Precise, delicate equipment is required because the tiny strands of metal may be 40 millionths of an inch or less in diameter—about one hundredth the thickness of a human hair. Use of the method has cast new light on the nature of the interatomic forces that give all metals their strength.

In whiskers, a metal exists in a perfect condition. In contrast, any ordinary piece of metal contains countless millions of structural imperfections. Under stress, these imperfections

Top photo, tiny iron whiskers, such as this one, are enabling scientists to better understand the forces that bind atoms together. **Bottom photo,** equipment used to stretch these whiskers.

govern how and when the metal will break. They mask any attempt to measure the much larger forces that hold the metal atoms themselves together. By conducting tensile tests on whiskers, where these imperfections do not exist, the individual atoms can be pulled far enough apart, without breaking, to get a measure of the interatomic forces. This enables, for the first time, a check of theories of interatomic forces.

In the whisker experiments, only a small force—less than one hundredth of an ounce—is required to pull the average whisker apart. This force, which must be controlled and measured with unusual accuracy, is obtained by a lightweight pendulum about 12 feet long. The whisker is "clamped" between the bob of the pendulum and a special "take-up" screw. As the screw is tightened, the whisker pulls the pendulum from its vertical position. Each millionth of an ounce of pull displaces the hanging pendulum exactly the same amount.

The stretch of the tiny whisker is measured by reflecting a beam of light from flat optical mirrors attached to the clamps at each end of the whisker, to form an "interference pattern." As the whisker stretches, the mirrors move and cause changes in the pattern similar to the changing "rainbow" colors seen

in soap bubbles or thin films of oil. These changes are electronically amplified and analyzed to disclose the amount of stretch. The technique accurately measures changes in whisker length down to less than one millionth of an inch. ■

Long Line of Luminaires

■ New York City's first major fluorescent street-lighting installation will also be the world's longest. As part of a "face-lifting" program for Manhattan's old and famed Third Avenue, 539 fluorescent luminaires have been installed along a 7½-mile stretch of the avenue, all the way from the Brooklyn Bridge to the Harlem River.

Spaced alternately at 100-foot intervals on both sides of the 70-foot avenue, each luminaire houses four 72-inch, 100-watt fluorescent lamps, providing an average of 0.8 foot-candles of illumination. Fixtures are to be mounted 26 feet above the street and tilted 30 degrees above the horizontal to illuminate the full width of the street.

Fluorescent lighting was selected for Third Avenue to give both quality of illumination and economy of operation. Each of the new four-lamp luminaires provides approximately the same light output as 1000 watts in incandescent lighting, but, in contrast, draws only 490 watts per luminaire. The fluorescent lamps are specially designed for street lighting service, starting and operating dependably at temperature as low as —30 degrees F. Nominal light output is 5300 lumens per lamp, but is higher at low temperatures, a characteristic that eases visibility problems of winter weather. ■

Below, Manhattan's Third Avenue before and after installation of new fluorescent luminaires. Along a 7½-mile stretch of the avenue, 539 luminaires have been installed for better lighting.

This ceiling-mounted radiographic tubestand will support an x-ray tube from the ceiling, and cover a room area of 12 by 16 feet. The overhead crane can be mounted on wall or ceiling. A spring balance system supports the tube so that it may be easily manipulated by hand. Power assist on the crane makes possible finger-tip control in moving the unit, so that the tube can be positioned quickly and easily.

Want Your Issues Bound?

In case you missed our notice in the November issue —you can now have your 1955-56 copies of the Westinghouse ENGINEER bound into a durable attractive book. You can choose from two methods:

1. **Permanent Binding of your own 1955-56 issues.** In this case, send your 12 issues (6 per year) to the address below and we will have them bound. The cost: $3.75. Missing copies will be supplied at 35 cents each, additional.
2. **Or, we can supply all issues and have them bound,** in the same binding as indicated above, for $6.00.

In either case, the volume will be complete with index and will be mailed postpaid. If we are binding your issues, allow several weeks for binding and delivery.

Send your issues, or your order to:

Westinghouse ENGINEER
P. O. Box 2278, Pittsburgh 30, Pa.

personality profiles

S. C. Townsend, W. E. Johnson and David H. Fax • C. G. Helmick
H. A. Zollinger • Y. S. Touloukian and R. L. Coit • J. E. Schrameck
and R. E. Kane • A. W. Smith

• All three of our authors of the homogeneous reactor article have been associated with the PAR Project since its inception. *S. C. Townsend* is the manager of the Atomic Power Department of the Pennsylvania Power and Light Company; *W. E. Johnson* is manager of the PAR Project at Westinghouse; and *David H. Fax* is assistant to the manager.

Townsend is a graduate of Lehigh University, where he obtained his BSEE in 1920. He joined the Pennsylvania Power and Light Company in 1924 and advanced through several engineering capacities to the position of Electrical Engineer in 1941. In 1954 he was given the additional job of managing PP&L's Atomic Power Department. He held both positions until February 1955, when he took over the atomic activities full time.

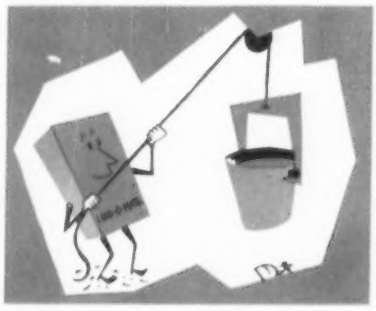
Johnson obtained his BS in Physics at Hamline University in 1937, followed by an MS and PhD in physics from Brown University in 1939 and 1942 respectively. From 1941 through 1947 he served on the staff of the physics department of Syracuse University, which he left to join the Oak Ridge National Laboratory. Here he worked in the field of radiation effects on materials. In 1949 he came to Westinghouse as manager of the solid-state section of atomic power activities at the Bettis Site. Since that time he has served as assistant manager of the physics department, manager of technical operations at the STR (submarine) Test Facility, and assistant to the Director of Development at Bettis. Since its inception in 1955 Johnson has been manager of the PAR Project, part of the Westinghouse Commercial Atomic Power Activities group.

Fax received his Bachelor of Engineering degree, major in mechanical engineering, from Johns Hopkins University in 1938. He spent three more years at Hopkins doing part-time graduate study and undergraduate instruction. Two more years were spent as a teacher in a war training program, also at Hopkins. From 1943 to 1946 he spent with an industrial concern doing blade-path design, and research in thermodynamics and experimental fluid mechanics. He returned to Johns Hopkins in 1946 as an assistant professor in mechanical engineering, where he spent the next eight years. During that time he also did consulting work for the U.S. Naval Engineering Experiment Station, Oak Ridge National Laboratory, the Atomic Energy Commission, Westinghouse, and others. In 1954 he joined Westinghouse at Bettis as an advisory engineer, and at the end of that year transferred to the study group that later became the Commercial Atomic Power Activities group.

• *C. G. Helmick's* second appearance on these pages comes fast on the heels of his first appearance in July of last year. When asked to elaborate on the things we said about him last time, Chuck admitted that he's sort of a "professional student." He is presently going to school nights, taking business courses at the University of Pittsburgh—it helps "balance" all that engineering he absorbed at the University of Michigan.

• *H. A. Zollinger's* first contact with Westinghouse was in the summer of 1950, when he came on the summer student training program. Apparently he liked it, and in 1951, upon his graduation from the Michigan College of Mining and Technology with a BSEE, he came back for more. He went from the Graduate Student Training Program to the General Mill Section in 1952 as a material-handling engineer—hence his interest in Load-O-Matic crane control of which he writes in this issue.

Howard's interest in material-handling problems also lap over into his spare-time hobby . . . a model railroad pike in his basement. His railroad specializes in coal handling; to name a few specifics, it will have an automatic rotary dump, an automatic coal tipple, and even a steam-generating plant to consume the coal that's hauled around.



• Industry and university authors join forces in the article on flash evaporators. *Y. S. Touloukian* is an associate professor of mechanical engineering at Purdue University, while *R. L. Coit* is an engineer at the Steam Division.

Touloukian is a graduate of Robert College, where he received his BSME in 1939. Two years later he earned his master's degree at M.I.T. and in 1946 his PhD from Purdue. He is presently an associate professor of heat transfer and thermodynamics at Purdue, and in addition the Director of the Thermophysical Properties Research Center. Since 1953 he has served as a consultant to the Westinghouse Steam Division on heat transfer, thermodynamics, and related problems. In addition to his teaching and research activities at M.I.T. and Purdue, he also has been associated with the Thermodynamics section of the National Bureau of Standards on a part-time basis since 1950, and serves as a consultant to several other industrial organizations and research agencies. Touloukian is the author of many major research publications on heat transfer and thermodynamics, and a member of numerous professional societies.

Coit, a mechanical-engineering graduate of the University of Oklahoma, joined Westinghouse as a research engineer at the Research Laboratories in 1947. Here he was largely concerned with combustion research. While at the Laboratories, he also earned his master's degree in mechanical engineering from the University of Pittsburgh. In 1953, he transferred to the development engineering department of the Steam Division. Here he was largely concerned with steam generators and evaporators. In 1956 Coit was made supervisor of the development section for heat-transfer apparatus.

• The authors of the compressed-air power circuit-breaker article are both Westerners—*J. E. Schrameck* from the University of Texas and *R. E. Kane* from the University of Wyoming, although he claims Nebraska as home.

Schrameck obtained his BSEE in 1937, followed by an MSEE in 1939. He came directly on the Westinghouse Graduate Student Training Program in 1939, and in 1940 went to work on compressed-air circuit breakers in the Switchgear Division. He was made a supervisory engineer in 1952, and two years later became manager of the compressed-air circuit-breaker engineering section.

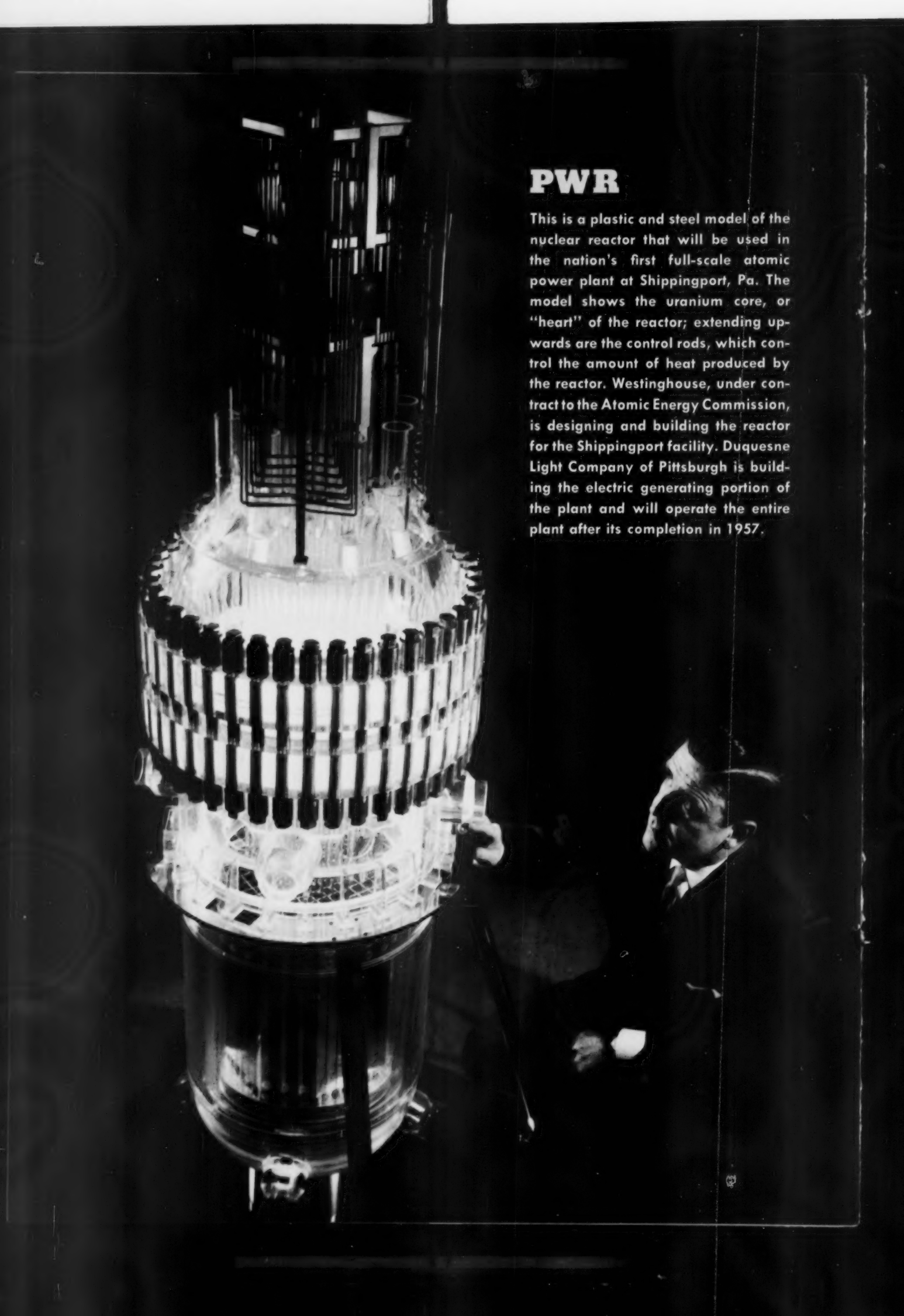
In his spare time, Schrameck is a fisherman—he always takes off the first day of trout season. His fondness for the class *Pisces* goes further than this; he also maintains a large aquarium in his home.

Kane graduated from the University of Wyoming with a BSEE in 1950, and shortly thereafter came on the Graduate Student Training Program. Late in 1951, he joined the compressed-air circuit-breaker engineering section of the Switchgear Division.

Kane spends much of his spare time in Boy Scout work. He's now an Assistant District Commissioner—and being a westerner, naturally enough heads up exploring.

• *A. W. Smith* started out to be a chemical engineer and wound up an electrical. It all came about when he was inducted into the Army after completing two years in chemical engineering at North Carolina State College. He was assigned to the Signal Corps, and spent one of his two years in the service at the University of Connecticut studying electrical engineering. As a result of this, he returned to North Carolina State to major in electrical engineering, and earned his BSEE in 1948. From there he came directly to the Westinghouse Graduate Student Course; after several months he joined the metal-working section of Industry Engineering.

Most of Smith's outside activities center around his four-year-old son and two-year-old twins. As an amateur photographer, his subjects are most often the children; and in his second hobby, woodworking, he spends a fair proportion of his time repairing toys and furniture "disassembled" by the children.



PWR

This is a plastic and steel model of the nuclear reactor that will be used in the nation's first full-scale atomic power plant at Shippingport, Pa. The model shows the uranium core, or "heart" of the reactor; extending upwards are the control rods, which control the amount of heat produced by the reactor. Westinghouse, under contract to the Atomic Energy Commission, is designing and building the reactor for the Shippingport facility. Duquesne Light Company of Pittsburgh is building the electric generating portion of the plant and will operate the entire plant after its completion in 1957.